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Beach ridge geomorphology of Kotzebue Sound: Implications for paleoclimatology and archaeology

Mason, Owen Kenneth, Ph.D.

University of Alaska Fairbanks, 1990

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BEACH RIDGE GEOMORPHOLOGY OF KOTZEBUE SOUND:
IMPLICATIONS FOR PALEOCLIMATOLOGY AND ARCHAEOLOGY

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BEACH RIDGE GEOMORPHOLOGY OF KOTZEBUE SOUND: IMPLICATIONS FOR PALEOCLIMATOLOGY AND ARCHAEOLOGY

A

THESIS

Presented to the Faculty
of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

Owen Kenneth Mason, M.A.

Fairbanks, Alaska

May 1990

Abstract

Beach ridges occur on all continents and record the horizontal addition of shoreface beyond the reach of storms. Improved cartographic methods in the nineteenth century allowed British historians to link shoreline changes with abandoned villages. This scientific trajectory was paralleled in the Bering Strait region from the 1880's to the 1930's. In the 1950's J. L. Giddings formalized "beach ridge archaeology" as a survey strategem using relative position to infer relative cultural chronology in northwest Alaska. Modern researchers use archaeological dates and data to document past climates or environments. At Cape Espenberg, on Seward Peninsula, my use of archaeological, stratigraphic, pedological, granulometric and photogrammetric data allows the delineation of 4000 years of coastal evolution. Four chronostratigraphic units are distinguished, using archaeological dates as minimum age assignments. Dune ridges formed in discrete intervals: 3300 to 2000 BP and from 1200 BP to the present; while low, berm ridges are predominant 4000-3300 and from 2000-1200 BP. The two differing types of ridges correspond to variable climatic conditions: dune ridges formed after higher storm surges and winter winds while the lower berm ridges are related to less intense storm surges. Coastal dunes at Cape Espenberg are soon altered by plant succession processes with distance from the beach. As primary dunes are eroded, a complex blowout topography results. Erosional processes in blowouts were monitored during 1987-1989, revealing substantial vertical changes, up to 10 cm of erosion per yr. These rapid changes have considerable influence on archaeological site stability. Studies of the gravel ridge systems confirm the proxy storm record apparent in the coastal dunes atop the beach ridges on the Seward Peninsula. The geoarchaeological methodology allows correlations between depositional units within nine of the principal beach ridge and chenier complexes of northwest Alaska. The onset of deposition was at 4000-3500 BP. The complexes at Cape Espenberg and Choris Peninsula contain elevated, broader transgressive ridge sets 3300-2000 BP and from 1100-200 BP, connected with increased storm activity in the North Pacific. Erosional discomformities between successive sets of beach ridges occur

at Cape Krusenstern at ca. 3000 BP and before 2000 BP. Between 2000-1000 BP extensive progradation occurred at nearly all complexes, indicating that less stormy conditions predominated.

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Acknowledgements

My research resulted from a fortuitous set of circumstances. First, early in 1986, my advisor, David M. Hopkins informed me that the National Park Service (NPS) would like interested parties to undertake Quaternary scientific research in conjunction with the archaeological survey in the Bering Land Bridge National Preserve (BELA). Subsequently, I was engaged as a survey archaeologist by Jeanne Schaaf for the 1986 field season. Both Dave and Jeanne provided the inspiration to study the sand ridges of northern Seward Peninsula. Dave has been a constant source of wisdom, critical acumen and editorial discipline.

In 1987 I returned to Cape Espenberg and visited the beach ridges of Choris Peninsula. In these efforts, the NPS provided fixed wing air support to Espenberg while the Alaska Quaternary Center and the University of Alaska Museum Geist Fund provided monies to reach Choris.

I must especially thank the Geist fund for several years of funding which enabled me to reach the field, to buy field equipment and to date samples. In 1988 I joined the NPS archaeological "Data Recovery" team at Cape Espenberg led by Roger Harritt and participated briefly as a volunteer in June 1989. Roger provided logistical support in 1988 and ready access to the data collected by the NPS. In addition, I enjoyed his comradery and criticism in the field; and that of the Data Recovery Lab Dragon, Theresa Thibault, and co-workers Richard Bland and Mark Pitkin.

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The Geology Department at UAF provided space to do grain size analyses, store samples and some office space. I also owe a debt of gratitude to my committee member J. E. Beget for assistance in obtaining a year-long research assistantship through

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The other members of my graduate committee made numerous important contributions, among them: W. R. Powers translated Russian passages on archaeological sites in Siberia and illuminated recent Soviet work on Eskimo archaeology; R.H. Jordan elucidated the history of research on the Canadian arctic beach ridges and engaged me in innumerable bull-sessions on the nature of archaeological data. J. E. Beget contributed to my understanding of the cyclical effects of climatic forcing over geomorphic processes by forwarding me numerous references. S. Naidu clarified the nature of sediment transport processes and performed mineralogical identifications.

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Two other dedications are in order: to my daughter, Monika, who has probably learnt more than she wants to know about sand and who looks forward anxiously to adding my samples to her sand box. And finally, I would like to acknowledge the unstinting and long-enduring support of my Father throughout the entirety of my graduate career.

Preface

The scientific importance of stranded "beach lines" (storm-deposited shore-parallel beach ridges) for documenting Arctic coastal changes was first recognized in the 1880's by the naturalist Edward W. Nelson (1899). Nearly eighty years later, James Louis Giddings, Jr. (1967) coined the phrase "beach ridge archaeology" to describe a site survey methodology using site position on sequences of beach ridges on the prograding shorelines of Kotzebue Sound. Giddings and his geological colleague, George W. Moore proposed in 1961 that beach ridge formation reflected large scale climatic variations in wind direction and intensity. However, neither Giddings nor Moore correlated deposits from more than one complex or developed a full chronology for Kotzebue Sound beach ridge history. My thesis seeks to extend and develop some of the questions posed by Moore and Giddings (1961).

My primary research aims are to:

(1) Define the climatic and geologic controls over dune and beach ridge formation in Kotzebue Sound;

(2) Provide a chronology of northwest Alaska beach ridge history during the late Holocene;

(3) Cross correlate deposits from all the major ridge complexes in northwest Alaska;

(4) Examine the implications of blowout evolution for archaeological sites and human occupation.

My research involved study of the surficial deposits and no drilling was done, due to logistic constraints. To characterize sedimentary deposits at Espenberg and Choris, I relied on a variety of methods including: aerial photo interpretation, granulometric determinations, pedogenic and stratigraphic descriptions, botanical observations and landform analyses. Chapters 2 and 3 present my methodology in full. Forty one radiocarbon assays from archaeological and geological context provided the primary means of chronological control (cf. Table II) at Espenberg and Choris. I collected more than 100 sediment samples for granulometric analyses to assist in the determination of sedimentary depositional environments, described in Chapter 2. To document blowout evolution I implanted about 100 survey markers and measured vertical elevations at intervals during 1987-1989, as described in Chapter 3.

The Study of Kotzebue Sound Beach Ridges

Beach ridge archaeology offered a pragmatic answer to the pressing methodological needs of the 1950's. At that time, the primary objective of most field archaeologists lay in chronology building, establishing the temporal succession of artifactual assemblages within discrete regions (Willey and Sabloff 1980). However, studies of beach ridge complexes using archaeological data may provide data for interdisciplinary studies related to paleoclimatology and landscape evolution, as described in Chapter 1.

Using former shoreline position as a predictive device is an easy method of locating sites and hypothesizing temporal successions, first recognized in arctic Canada by Mathiessen (1927) in the 1920's. As early as 1930 Henry B. Collins (1937) used position on a beach ridge sequence to estimate relative age, among a series of successively landward settlements on the Gambell foreland on St. Lawrence Island. After several seasons of work in 1956-62, Giddings (1967) became aware that variable numbers and configurations of ridges had accreted at differing locations in Kotzebue Sound. However, the geologic and climatic processes underlying ridge formation remained unstudied. Fortunately for Giddings, some preliminary coastal process studies were initiated in the early 1960's by George W. Moore, a geologist commissioned by the Atomic Energy Commission to study effects upon the coast of a proposed nuclear blast intended to construct a port facility north of Cape Krusenstern. Moore and Giddings (1961) formulated a hypothesis to explain beach ridge progradation at Krusenstern as a response to variable positions of the Arctic Front during the late Holocene.

Though Moore and Giddings published a short abstract on the subject, they did not further develop their hypothesis on climatic controls over beach ridge formation. After Giddings' death in 1964, interest in beach ridge origins and archaeology waned. Douglas D. Anderson, a young Ph.D. student of Giddings at Brown University, assumed responsibility for completing Giddings' unfinished projects which included a major excavation at the well-stratified Onion Portage site and the report on Cape Krusenstern. However, Anderson conducted no new excavations at Cape Krusenstern or any new analysis of Krusenstern materials and the final report did not appear until over twenty years after Giddings' death (Giddings and Anderson 1986). Chapter 1 describes the development of beach ridge studies in Alaska and provides a summary of related pioneering studies in Britain, Louisiana and elsewhere.

In northwest Alaska, beach ridge plains occur at seven coastal inflections between Bering Strait and Point Hope (Fig. 1.2). The geomorphic features of a particular beach ridge complex are determined largely by the grain size and lithology of source materials. Beaches of the southeast Chukchi Sea coast are divided into two lithic regions: (1) sandy beaches prevail along much of the north Seward Peninsula coast, at Sisualik near the mouth of the Noatak River and along parts of the Baldwin Peninsula and (2) gravel prevail along beaches along the remainder of the coast.

On the sandy coasts of Seward Peninsula, beach ridges are often ornamented with dunes. Thus, investigations into the history of progradation involve several steps: distinguishing differing modes of formation of the deposits (marine and/or eolian), interpreting the complex internal stratigraphy of the dunes: describing primary structures, paleosols and cryogenic alterations; and, finally, analyzing the dissection of the beach ridge due to biological factors. Chapters 2, 3 and 4 describe these matters more fully.

I undertook field studies at two beach ridge complexes, Cape Espenberg and Choris Peninsula during 1985-1989, using a variety of techniques and benefiting from archaeological investigations conducted simultaneously by the National Park Service in the Bering Land Bridge National Preserve. The two complexes contain deposits of sand and gravel which are the two principal sediments within the Kotzebue Sound littoral zone. Because sand and gravel respond differently to wave and wind energy (cf. discussion in Chapters 2 and 4), the studies at the two complexes are complementary The principal area examined in this study is the Cape Espenberg spit, located at the northern extreme of the Seward Peninsula, straddling the Arctic Circle (Fig. 2.2). Oriented roughly west to east, the Cape Espenberg spit extends about 30 km longitudinally and varies 1 to 2 km in width. About 4000 years of Holocene history is recorded at Espenberg, the subject of Chapters 2 and 3. Choris Peninsula lies 85 km southeast of Espenberg. Three separate gravel ridge complexes formed within former embayments of the low bedrock knob of Choris, as described in Chapter 4.

A number of boundary conditions must be met in order for a progradational coastal feature to form. Three requirements are paramount: low levels of tidal fluctuation, a slow rate of sea level change and a surplus of sediment. If all these preconditions are met, the net result is a beach ridge, beyond mean high water. Chapter

2 concerns the origin, evolution and history of the Cape Espenberg spit, the sandy beach/dune ridge system. Boundary conditions and sediment sources, offshore and terrestrial, are addressed in this context. Chapter 3 discusses the degradation of dunes by the development of blowouts and touches on the significance of this process for archaeologists, as well as describing archaeological sites in the Espenberg dunes. Chapter 4 presents the results of my research on Choris Peninsula. Chapters 5 and 6 relate my work to the published and unpublished radiocarbon dates and stratigraphy from other northwest Alaska complexes; supplemented by my own photo-interpretation of ridge patterns at Cape Krusenstern, Wales, Cape Nome and Pt. Hope.

The formation of beach ridges and dunes atop ridges may be related to seasonal variation in climatic conditions, primarily due to the frequency of storm surge conditions and periods of intense winds. Storm surges occur with greatest frequency and intensity during the fall months, often before the seasonal ice pack has formed. Sea surface elevations of up to 5 m occur along the Seward Peninsula coast, with major erosive effects on the beaches. High winds are common throughout most of the year, except in July. Alternations in storm intensity are, ultimately, related to macroscale controls on climate and show a clear trend throughout the late Holocene (Chapters 2, 5 and 6).

The delivery of sand onto the beach beyond wave attack, at least seasonally, provides an opportunity for dunes to form atop the beach ridge. The development of dunes involves the presence of grasses and other plants which fix the dunes and further vertical growth. With time, pedogenic processes form characteristic soil horizons. The disruption of the vegetation cover produces blowouts (deflation hollows). Blowout development proceeds in a recognizable sequence, from single blowouts to nested until extensive areas of deflation result. Chapter 3 discusses the evolution of blowouts and their geo-archaeological significance.

The construction of 5 to 6 m high coastal dunes at Espenberg enhanced its attractiveness as a site for human settlements. Discussion of the geoarchaeology of Cape Espenberg in relation to topography is covered in Chapter 3. Site discovery at Espenberg depends largely on disruptions in vegetation cover, as noted by Giddings (1967). Due to this circumstance, I monitored blowout elevation changes in order to quantify erosion rates. In two years of record (1987-89) I found removal of up to 10 cm of sand from some blowout basins (Chapter 3).

As noted above, beach ridge plains occur at seven principal locations in Kotzebue Sound. By applying the methods used at Espenberg, I defined depositional units at the Chukchi Sea beach ridge complexes at Choris, Krusenstern, Wales, Sisualik and Pt. Hope and at the two Bering Sea complexes at Safety Sound and Gambell. The cumulative record is described in Chapter 5. Special attention is given in Chapter 6 to Gambell and Krusenstern, where I re-defined some of the units originally described either by Collins or Giddings. Chapter 6 is a collaborative effort, that draws upon the foreign language abilities of Stefanie Ludwig to translate the German works of Hans Georg Bandi who excavated on the Gambell beach ridges in the late 1960's-1970's. Ludwig summarized her translations in several pages and added some observations about gravel beach ridge formation at Krusenstern. We found that it is possible to turn archaeology on its end and to connect the depositional histories of Gambell and Krusenstern into the common story of Holocene storm patterns throughout northwest Alaska.

In summary, the climatic picture offered by my researches reveals a series of high intensity storm events, separated by periods of less intense storms (Chapters 2, 4, 5 and 6). The high intensity events result in dune construction and occur at 3300-2000 BP and at intervals from 1200 BP to the present. Significantly, the Neoglacial period and the Little Ice Age cold periods are associated with these anomalous wind events. Low ridges with wide swales are indicative of low storm recurrence intervals (Chapters 2 and 3) and are dated to between 2000-1000 BP and before 3000 BP. Further insight into the causes of changes in the storminess of the Bering and Chukchi Seas is sought by comparing beach ridge records with Holocene glacial and tree-ring records in Alaska and historic storm records in China (Chapter 2).

The organization of the thesis reflects my intention to submit the individual chapters as articles in various professional journals. Consequently, some repetition in material and focus was necessary. Chapter 1, a history of the beach ridge method and its applicability world wide, is aimed at *Current Anthropology*, *Geomorphology* or *Earth Surface Processes/Landforms*. The lengthy description of the sedimentary budget and evolution of the Cape Espenberg spit in Chapter 2 will be submitted to the *Journal of Coastal Research* or *Zeitschrift für Geomorphologie*. Chapter 3, a description of the processes of blowout evolution and its geoarchaeological implications at Espenberg, will be sent to either the *Journal of Field Archaeology* or *Catena*, a journal that has published many works on eolian deflation. Chapter 4 on the gravel beaches of Choris is oriented toward *Arctic*, since the study has a local focus. Finally, the concluding chapter 5 is destined for submission to *Quaternary Research*, in view of its focus on the Holocene climatic record in most of the northwest Alaska beach ridge complexes. The Appendix has been submitted and accepted (J. Donahue 1990, personal communication) for publication in the journal *Geoarchaeology*, which was selected since we use geoarchaeological methods to reexamine the archaeological record at the beach ridge complexes at Cape Krusenstern and Gambell. Though the style guide-lines for each journal vary considerably, I generally follow the style guide lines for QR, especially in the references which are presented at the end of the entire thesis. Figures are integrated into the chapters and are usually presented only once, though in submission they will be duplicated. Tables, including radiocarbon date lists, are placed at the end of the thesis.

Chapter 1

The Geoarchaeology of Beach Ridges:

Studies of Coastal Evolution

using Archaeological Data.

Introduction

The scientific discovery of coastal evolution during the late nineteenth century paralleled Darwinian evolution, yet occurred in an un-dramatic, largely parochial manner. Armed with accurate maps, observers such as engineers, naturalists and historians compared sequential map sets along the coast, finding that significant changes had occurred in the last several hundred years. During the last 50 years, the dynamism of shoreline changes has claimed wide scholarly attention, especially in light of the catastrophic effects of hurricanes on now well-populated resorts on formerly remote barrier islands of the eastern United States. Doomsday predictions of massive coastal erosion due to the greenhouse effect fuels modern coastal research (Gibbs 1984, Titus 1987).

From the beginning, geomorphologists have grappled with the problem of how to obtain greater time depth in documenting coastal evolution. Nineteenth century investigators in widely separated environments from the Arctic to the English Channel observed abandoned settlements along the coast and inferred relative changes in shoreline position. From such embryonic observations, the method of "beach ridge archaeology" was brought to fruition in Northwest Alaska by J. Louis Giddings during the 1950's.

For archaeologists, multi-faceted interpretations are based on pre-historic shifts in the relative position of the coast, ranging from the origins of domestication (Binford 1968) to the processes of intercontinental migration (Masters and Fleming 1983). Archaeologists acknowledge the possibility that eustatic sea level changes render a major part of the prehistoric record invisible (Yesner 1980). In a sense, coastal archaeology requires a synthesis of geological and archaeological techniques (Kraft et al. 1985).

Beach Ridges and Their Significance

A beach ridge is an increment of shoreface, added beyond the reach of storms, preserved on a coastline with stable sea levels or uplifted by tectonic or isostatic forces. Typically, the addition of shoreface, that is, progradation, is associated with meso- or microtidal conditions (Hayes 1979), the presence of abundant sediment in the near shore zone and a balance between the long-term trend of sea level fluctuations with regional storm and wave climate (Curray 1964, Kraft and Chrzastowski 1985).

Seventy years ago D.W. Johnson provided a compendium on "shore ridges and their significance," formulating a set of principles for beach ridge studies. Johnson (1919: 404ff) also provides a useful review of nineteenth century beach ridge studies. Several of Johnson's axioms remain relevant today:

(a) a single ridge is constructed by many storm events and should be regarded as a composite of events rather than as a reflection of a particular shoreline;

(b) the height of ridges cannot be assumed to provide sea level records if tectonic uplift or subsidence has occurred;

(c) the rate of beach ridge formation is variable and requires repeated observations or fixed chronological markers;

(d) erosion in one part of a beach ridge complex may be coupled with deposition in another part of a complex.

In the last thirty years, records from beach ridges have led researchers to postulate shifts in the position of prevailing winds (Moore and Giddings 1961, Curray et al. 1969), infer the timing of the El Niño phenomenon (Richardson et al. 1983, Sandweiss 1986), to determine sea level history (Moore 1960, Searle and Woods 1983, Fairbridge 1986), the rate of isostatic rebound (Andrews et al. 1971) and the solar-linked periodicity of storms in the Arctic (Fairbridge and Hilliare-Marcel 1977). Tanner (1988) provides an update for the wide range of applicability of beach ridge studies. The coupling of archaeological data with its geological context provides a wide canvas for scientific inquiry. In this chapter, I explore the history of beach ridge studies and sample some of the most significant results of this research.

The Birth of Beach Ridge Studies: British Precursors

Some of the first efforts to use cultural evidence to infer changes in coastal position date from the 1850's. Much of this work resulted from improved mapping and geodetic leveling procedures. With detailed maps, British researchers soon became fascinated with the history of the Dungeness foreland (Fig. 1.1), a gravel beach ridge plain on the English Channel coast, only about 100 km SE of London. Using the map sheets of the Geological Survey of Great Britain, J.B. Redman (1854 in Johnson 1919) observed about 1.6 km of progradation from the town of Lydd since the time of Queen Elizabeth (1600 AD). Redman also undertook field observations and calculated an average annual rate of progradation ("5 to 6 yards"). Other researchers counted the number of ridges, with variable counts emerging--up to a total of 135.

Historical records were marshalled into the service of geomorphic history at Dungeness with Appach's hypothesis that the foreland did not exist at the time of Caesar's invasion of Britain, 55-54 BC. Johnson (1919:426) rejected this hypothesis based on the fact that Roman artifacts and farms had been found on Romney Marsh, the oldest portion of the foreland. Medieval records indicate that a section of the foreland had been dyked at 774 AD and that 23 ridges were added from before 774 and 1900 AD.

In the twentieth century, Dungeness continued to interest British geomorphologists and historians, who used the context of archaeological remains to date its geomorphic evolution, before the advent of radiocarbon dates. Examination of Saxon charters aided in re-constructing the extent of Romney Marsh, landward of the foreland (Steers 1964). Lewis (1932) provided the first detailed reconstructions of the successive positions of the English channel shore. Subsequently, Lewis and Balchin (1940) used the precise leveling data to infer sea level history at Dungeness:

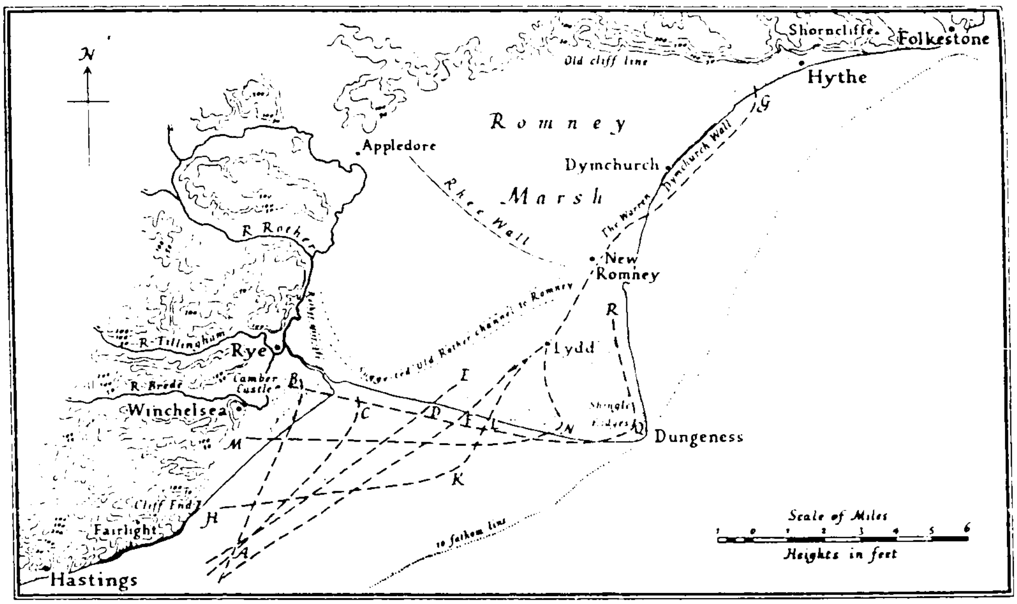


Fig. 1.1. Map of the evolution of the shoreline at Dungeness foreland, southern coast of Britain, SE of London. From Lewis (1932). Dungeness foreland is the site of the earliest beach ridge archaeological study.

(1) 2-3 m below modern at 2000 BP (ie., Roman times)

(2) 0.3 m lower than modern at 800 AD

(3) same level as today in 1300 AD

(4) increase of about 0.3 m since 1500 AD

The Dungeness chronology was not systematically addressed until the 1950's soil surveys which produced detailed maps (Green 1968) and a radiocarbon date list (Smart 1964). Cunliffe (1980) synthesizes the modern data with Lewis' reconstructed shorelines to produce a depositional history. Initially, a longshore spit formed before 2000 BP, but sea level remained about 2 m below modern levels during Roman times, based on Cunliffe's excavations of a Roman fort. Major re-adjustments in shore orientation occurred between 300-600 AD, accompanied by silting-in of the Romney estuary. The port town of Hythe, to the northeast of Dungeness, was moved several times during early medieval times. In the thirteenth century major transformations in the evolution of the foreland occurred due to the impact of several severe storm tides in 1250 and 1287 AD. As a result, the headland itself advanced, several through-flowing channels were re-oriented and high beach ridges were constructed (+6.0 m above mean sea level, the highest on the foreland). After the 13th century storms, Romney marsh rapidly silted in and furthered the process of land reclamation.

Though not explicitly termed a methodological approach, British research at Dungeness uses the principal postulates of "beach ridge archaeology:"

(a) Coastal settlements were sited in reference to maritime access;

(b) Sites will be younger toward more recent geomorphic features;

(c) Dates of cultural occupation provide minimum age assignments for depositional history;

(d) Shifts in ridge alignment provide clues about wind direction;

(e) Heights of ridges allow inferences about relative sea level changes.

The Mississippi Delta: Archaeology in the Service of Geology

Shore-parallel ridges, similar to beach ridges, are also common near river deltas and are termed chenier (from the French, *chêne*, "oak") ridges (Reineck and Singh

1980). Though the genesis of cheniers remains controversial (Otvos and Price 1979), the history of the study of chenier ridges bears a close resemblance to that of beach ridges and shows the necessity of cross-fertilization between Quaternary geology and archaeology.

During the 1930's Louisiana geologists studying modern deltaic environments of the Mississippi River struggled with the perennial problem of estimating rates of deposition (cf. review in Gagliano 1984). Readily observable archaeological data such as "kitchen middens" and diagnostic, temporally specific ceramics provided a means of estimating relative time and, hence, change within individual delta lobes. Geologists surveying the delta encountered numerous shell middens and used them as indicators of subsidence (Howe et al. 1935). Archaeological sites commonly occur on topographically higher levees at river's edge or within stranded shore-parallel ridges (cheniers). F. B. Kniffen (1936), one of the first to survey the Mississippi delta mounds, recognized the potential of archaeological sites in geomorphic research, for "along the natural levees of the main stream or on the major distributaries were the sites favorable to human settlement. As the flow of fresh water was diverted to new channels, the older ones lost their habitable qualities." McIntire (1958) produced a voluminous body of site-specific data bearing on the abandonment of various sub-deltas, using diagnostic artifacts to estimate the age of depositional units. With the advent of radiocarbon dating in the 1950's, the two bodies of data could be integrated to reconstruct culture history, shoreline and deltaic evolution. Gould and McFarlan (1959) document four principal series of cheniers dating from 2800, 2100, 1200 and 650 years BP which implies that chenier construction occurred only within discrete periods of heightened storminess or low sediment influx.

A complement to the chenier record may be derived from studies of alluvial history from the Upper Mississippi valley. Knox (1988: 294-5) reports a sharp rise in flood magnitude about 3000 BP, a brief period of small floods after 2000 BP and larger floods after 1000 BP. By comparing chenier/beach ridge records with alluvial chronologies and pollen evidence, we can integrate several proxy climatic records and obtain a more clear paleoclimatic signature.

The cross-fertilization between Louisiana geology and archaeology continues to the present time. The Louisiana geological literature routinely uses archaeological cultures to distinguish paleo-shorelines, ie. as in the "Teche" shoreline (Penland et al. 1987) or to provide chronological limiting dates, as Gerdes (1985:124) does in referring to the age of the Caminada-Moreau beach ridge plain as less than 1000 years, due to a lack of archaeological remains earlier than 1200 AD.

Gagliano (1984) provides an explicitly geoarchaeological approach to deltaic and coastal environments. Using a systems approach, Gagliano summarizes data on the depositional environments for the entire Gulf of Mexico coast and then considers the influence of eustatic sea level changes, at both the long term and within the site specific context. Still, Gagliano's aim seems site-contextual and Quaternary scientists could reveal a paleoclimatic, time-parallel stratigraphic perspective.

Alaskan Precursors: Edward W. Nelson and Henry B. Collins

The American frontier provided a scientific *tabla rasa* for several generations of professional observers financed by the Smithsonian Institution's Bureau of Ethnology. Edward W. Nelson, an ornithologist, accepted a post at St. Michael, Alaska, on the shores of the Bering Sea in the 1870's. During his extensive travels, Nelson (1899) visited numerous Eskimo settlements along the shores of western Alaska and Siberia. At one stop, Nelson observed a series of four abandoned settlements, unrelated to the present outlines of the Chukchi Sea coast. At this locality near Cape Vankarem, on the Chukotsk Peninsula, on the Soviet side of Bering Strait (Fig. 1.2), Nelson (1899:265-266) sketched the outlines of beach ridge archaeology, proposing it on the basis that "the western Eskimo have an almost invariable custom of building their villages facing the water and parallel with the shore line." Using his observations on the orientation of houses, "well-marked ancient high waterline" indicators and stranded beach gravels, Nelson proposed a chronological relationship between the four villages, assuming "gradual uplifting" of the land since occupation. Nelson's observations remained buried within his voluminous ethnological treatise, for as he lamented (1899:266):

> The severity of the Arctic climate on this bleak coast renders it very difficult, if not impossible to make an estimate...as to the length of time that has elapsed since an ancient site was occupied. If data were at hand to estimate the rate of the rise of the land on the northwestern Alaska and Siberian coasts, we would have a key to the approximate age of the villages ...at Cape Wankarem [sic] and probably to the age of numerous other settlements

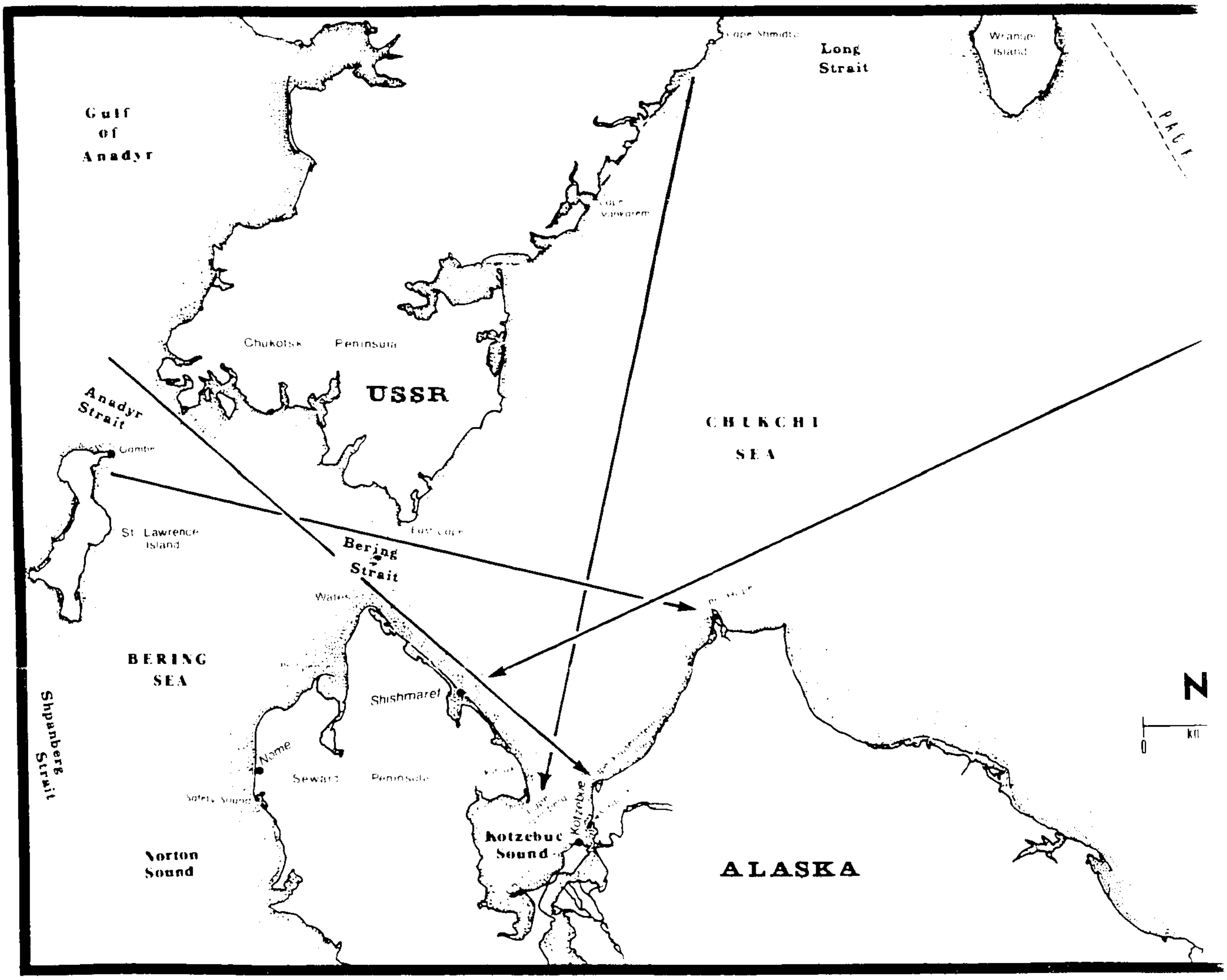
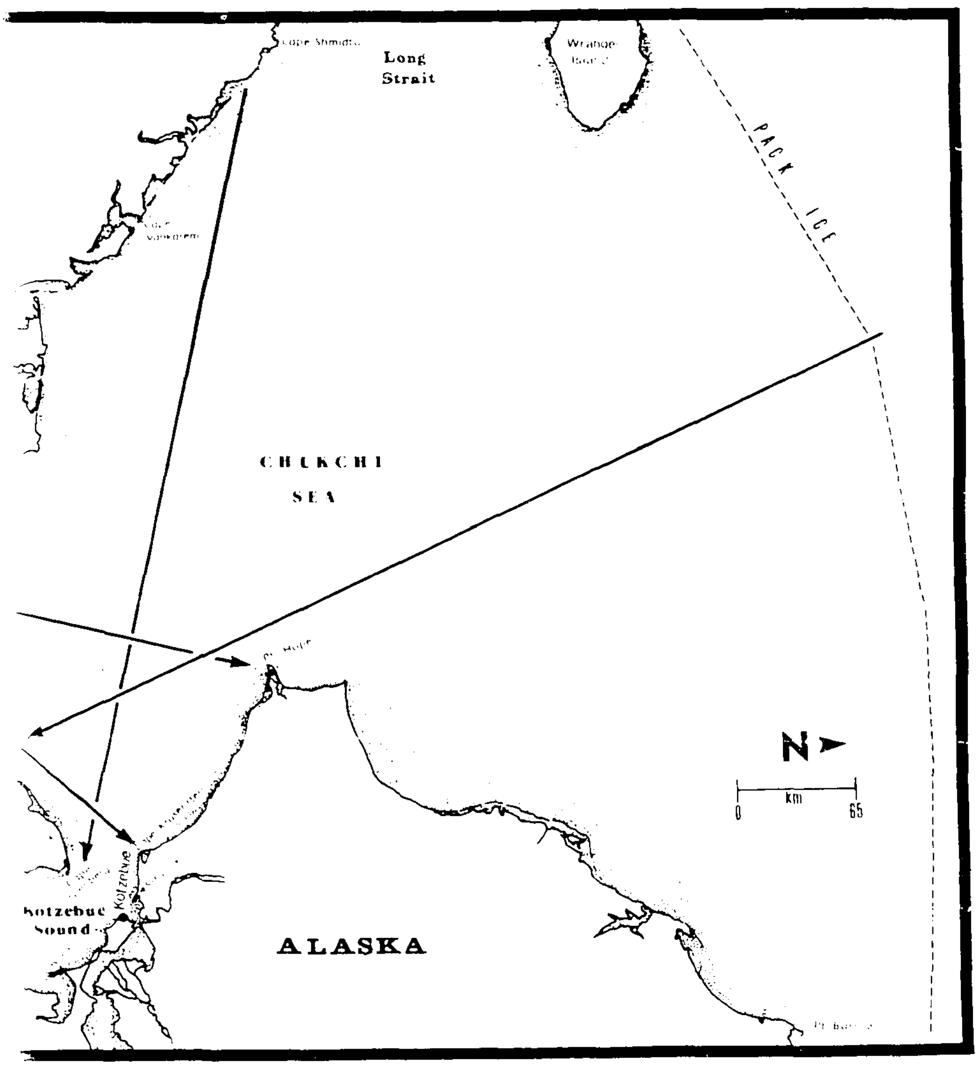


Fig. 1.2. Beach ridge plains in the Chukchi and Bering Seas. Lines represent maximum wind fetch available for wave generation (see below, Ch. 2).



chi and Bering Seas. Lines represent
e generation (see below, Ch. 2).

along the same shore.[1]

Apparently, Nelson's observations went unnoticed by Arctic archaeologists. Finally, in 1930 Henry B. Collins (1937), also backed by the Smithsonian, independently observed Eskimo site preferences and re-invented the beach ridge method during the course of his own research on St. Lawrence Island (Fig. 1.2). Collins used the position of abandoned villages on the Gambell beach ridge plain to infer relative age and described topographic differences within the ridge system. However, Collins did not use such descriptions in a systematic manner to relate topographic changes to changes in depositional regime or climatic parameters. Site position presented only a survey strategem.

Working at the gravel ridge spit at Point Hope (Fig. 1.2) in 1939-1941, Helge Larsen and Froelich Rainey observed geomorphic processes but made no attempt to integrate geology into the purely archaeological goals of their excavations of the enigmatic Ipiutak culture. Larsen and Rainey (1948:19) did hypothesize (probably mistakenly) that ice push during the winter was the agency responsible for adding ridges to the spit on its south margin while wave-induced erosion during open water periods was eroding its northwest aspect. As at Gambell, the oldest remains at Pt. Hope lie farthest from the actively building portion of the spit on south. But, though "many parallel old beaches form the peninsula...a uniform succession of house pits and villages" could not be recognized by Larsen and his co-workers (Giddings 1967:18). Since the depositional regime at Pt. Hope spit apparently has not shifted through time, only by measuring the widths of inter-ridge swales can the Pt. Hope ridge system be subdivided into a coherent stratigraphic history (Mason this volume, Ch. 5).[2]

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[1] Soviet investigations (Dikov 1977: 198-199) from the late 1950's confirm some of Nelson's interpretations at Cape Vankarem, yielding radiocarbon dates of about 870± 50 B.P. (MAG-201) for one of the sites landward of the present shore, indicating that massive erosion and re-deposition after occupation by Birnirk and Punuk cultures. A similar depositional history is known from other Chukchi Sea locations.

2 The subtlety of the Pt. Hope system could not be recognized until the 1967 mapping project (Hosley 1972) undertaken because of the planned re-location of Pt. Hope village. In fact, Sharma's (1972) work at Pt. Hope involved the first purely geological excavation of beach ridges in Kotzbue Sound.

The Development of the "Beach Ridge Dating" Method

In the 1950's James Louis Giddings, Jr. realized the potential of beach ridges as an archaeological research tool. Giddings had accompanied Larsen and Rainey to Pt. Hope while he was a graduate student at the University of Arizona. Giddings (1964) continued to explore western Alaska during the late 1940's-1950's, setting forth the rudiments of Eskimo cultural chronology based on a series of excavations near Cape Denbigh in northeast Norton Sound (Fig. 2.1). In 1956 Giddings returned to Kotzebue Sound, probing into a series of nine beach ridges within a sheltered cove on the western shore of Choris Peninsula. At Choris, Giddings (1967:18) "first acquired faith in beach ridges as time markers, observing the regularity of cultural succession...envision[ing] in them a kind of horizontal stratigraphy that might carry with it a built in calendar." Giddings noted this as an hypothesis, requiring testing, and observed that beach ridge formation rates varied from place to place.

Upon his return to Brown University from Choris in 1956-1957, Giddings grew convinced of the potential for careful study of other beach ridge complexes, applying to the American Philosophical Society for financial support. In his grant application Giddings termed his search "beach ridge dating" and thought he was blazing a new path since he could find "no one [who] seemed to know much about the mechanics of formation of these beaches or anything at all about the time required for one beach crest to supplant another" (Giddings 1986 in Giddings and Anderson 1986:6).

Giddings' 1958 season in Kotzebue Sound proved to be monumental in scope--circumnavigating the entire southeast shore of the Chukchi Sea from Deering to Cape Espenberg, then to Shishmaref, up to Sisualik spit and finally to Cape Krusenstern (Fig. 2.1). At Cape Espenberg, a sandy spit, previously disregarded by archaeologists, Giddings (1967:25) found the confirmation of the beach ridge method that he sought--a succession of old to young sites matching the ridge succession, although lacking direct radiometric control at the time. However, the "ever-moving dunes" at Espenberg Giddings felt (1967:25-26) would render discovery of actual house depressions difficult. Further, he observed that earlier ridges at Espenberg had been "covered over by later beach ridges, protruding at an angle at a lower elevation farther toward the eastern tip of the peninsula."

During the next four years from 1958 to 1962 Giddings turned to Cape Krusenstern and conducted an extensive pedestrian survey and excavation program. In the course of this research, Giddings had the good fortune to encounter George W. Moore, a USGS geologist engaged by the Atomic Energy Commission to study the geomorphic effects of a proposed atomic blast to create a deep water port ("Project Chariot") near Ogortoruk Creek, on the north shore of Kotzebue Sound. In examining potential impacts, Moore examined the longshore transport system of the entire coast from Sisualik to Point Hope. Moore's (1960, 1966) observations were as seminal as those of Giddings and provided a baseline for beach ridge formation studies within Kotzebue Sound. Moore and Giddings (1961) eventually co-authored an abstract postulating that beach ridges at Krusenstern and Sisualik respond to the shifts in the position of the Polar Front.

The four years of Giddings' research at Cape Krusenstern involved extensive excavations of hundreds of archaeological features but produced a limited suite of radiocarbon dates (n=33) on only seven of the 114 ridges. Giddings never formalized his stratigraphic nomenclature and only the barest outlines of his system are published (Mason and Ludwig, in press; this volume, Appendix). Unfortunately, Moore and Giddings did not have the opportunity to write a detailed geological interpretation of the Krusenstern succession (Moore 1989, written communication).

After 1962 Giddings turned inland and excavated Onion Portage, a well-stratified alluvial site on the Kobuk River paralleling the cultural chronology at Krusenstern. Subsequent to Giddings' death in 1964, the practice of beach ridge archaeology in Kotzebue Sound lapsed. Giddings' successor, his graduate assistant, Douglas D. Anderson, also of Brown University, continued to work at Onion Portage and provided a synthesis of both inland and coastal regions, linking the undated portions of the beach ridge sequence (Giddings and Anderson 1986) to the cultural chronology of the Kobuk River (Anderson 1988).

In brief, the depositional history produced by the Moore (1966) and Giddings (1966) for Krusenstern reveals six units, separated by three prominent disconformities. Distinctive regionally distributed archaeological cultures provide the cultural sequence while radiometric dates from Onion Portage flesh out the chronology. The onset of deposition at Krusenstern is thought to lie at 4000 BP, based on the occurrence of the microlithic artifacts of the Arctic Small Tool tradition on ridges 102-104. At 3000 BP the enigmatic Old Whaling culture was established on the 53rd ridge, after which time a major erosional event occurred. Ridges 36-44, estimated to be about 2500 yrs old, contain the distinctively linear and check-stamp decorated pots of the Choris and

Norton peoples. About 2000 BP an erosional regime dominated the Krusenstern foreland while conditions favoring progradation became prevalent 2000-1000 BP at the time of the Ipiutak culture. The settlement of western Thule people was contemporaneous with a series of erosional events that began 1200 to 1000 BP and resulted in the re-distribution of gravels southeastward; a process which has continued until the present.

Moore (1960) postulated that the heights of individual ridges provided an estimation of sea level. The highest ridges occurred at 1700-1300 BP while the earliest ridges at 4000 BP seemed to have subsided. Later, Hopkins (1967:86ff) used Krusenstern as a type section for the Holocene establishment of near modern sea levels in Alaska.

The history of beach ridge studies in Alaska has progressed full-circle. Initially, Nelson's (1899) recognized that relative shore-line changes were an indication of geomorphic processes. In the 1930's-50's Collins' and Giddings' used relative ridge position as a site survey device, by the 1960's Moore and Giddings (1961) proposed that climatic conditions controlled deposition at the various complexes; but due to Giddings' death in 1964 the project remained uncompleted. Aspiring to complete their work, my work (Mason this volume, Chs. 2-4) at Cape Espenberg and Choris Peninsula provides cross-correlations of depositional units from several complexes and reveals a common Holocene history. Inquiries into beach ridge geomorphology have a similar history in Arctic Canada and Scandinavia, but researchers rarely attach any paleo-climatic significance to the ridge sequences.

Distinguishing Raised Beaches from Beach Ridges: Canada and Finland.

Successions of raised beaches are also common along the shores of the Canadian archipelago and Hudson Bay. The geomorphic significance of elevated shore-parallel ridges was appreciated by Therkel Mathiassen (1927:8ff) during his excavations at Naujan on the Melville Peninsula during the Fifth Thule expedition of 1921-1924. Ascribing present ridge position to uplift, Mathiassen set the stage for successive generations of Arctic archaeologists. However, too frequently high Arctic ridges are confused with the purely depositional beach ridge, as used interchangeably by Collins (1962:128-129). In many cases, the raised beaches of Canada are isostatic in origin (Hilliare-Marcel and Fairbridge 1977), rising above sea level as the lithosphere rebounds, relaxing in the absence of overburden pressure associated with continental glaciation of the late Pleistocene (Andrews 1986). Thus, beach ridges are deposited in the littoral zone and uplifted gradually. The occurrence of archaeological sites on the ridges allows geologists to estimate the continuing rate of isostatic uplift (Andrews et al. 1971).

In light of the constancy of isostatic uplift, Canadian archaeologists use beach ridges primarily as a survey strategem and/or chronological referent. For example, at Port Refuge on Devon Island, McGhee (1979) used the extrapolated uplift rate of Andrews et al. (1971) to produce an age estimate of 5000-4000 BP for a Paleo-Eskimo occupation, located on a 22-25 m high ridge now 600 m inland . The beach ridge plain at Igloolik, North West Territories has 60 to 130 gravel ridges over a gradual slope, allowing Melgaard (1962) to delineate a chronology based on the relative position of pre-Dorset and Dorset culture sites. Maxwell (1976) also used the differential occurrence of cultures by ridge elevation as a purely classificatory device. Even in the recent work of Bielawski (1988) ridge altitude assists merely to distinguish archaeological cultures.

Beach ridge plains prograde slowly in the high Canadian arctic because of low rates of sediment delivery to the near shore zone. Taylor and McCann (1983:68) report on northern Somerset Island that only four ridges have been added since 1420 ±50 BP (GSC-2704) while on southern Ellesmere Island only two have accreted in the last 500 years. Studies of modern processes indicate ridges vary from 0.5 m in height, if deposited during low energy, fair weather conditions, to over 4.0 m in height, if deposited during high energy storms.

Though the survey-oriented methodological approach of many Canadians is effective, a considerable amount of micro-climatic information remains untapped. For example, at Port Refuge (McGhee 1981:Fig. 4), the apparent variations in ridge and swale width could be related to meteorological controls over ridge formation, following Tanner's (1988) suggestions. The work of Stewart and England (1983) illustrates an approach based on collection of a series of driftwood samples from beach ridges for radiocarbon assay from the now ice-bound northwest shore of Ellesmere Island. Assuming driftwood deposition implied direct marine deposition, it is possible to infer times of open water and climatic change.

In Labrador, Fitzhugh (1972) combined the traditional isostatic rebound paradigm with an ecological perspective to infer the consequences of variable coastal positions. Using dated sites (n=15) from raised beaches and limited geological data (n=5), Fitzhugh (1972:27ff) constructed an uplift curve for Labrador useful in predicting age of undated sites by elevation by interpolation. Fitzhugh extended his analysis to use reconstructed sea position to infer substantial changes in the availability of marine mammals.

Researchers (Clague et al. 1982) on the British Columbia coast use a combination of archaeological and geological data interchangeably to document the complex interplay of eustatic sea level changes, tectonism and isostatic compensation. Though archaeological sites in British Columbia are routinely used as a elevational datum, little use of beach ridges is made, due to the rare occurrence of prograding deposits; a notable exception being the Graham Island spit unstudied as yet. In Southeast Alaska, Mobley (1988) similarly attempts to delineate sea level changes using a limited sample of dated archaeological sites.

Finnish researchers record the occurrence of archaeological sites atop the uplifted shores of the Baltic Sea to reconstruct paleo-shorelines (Eronen 1983:201-3). Similar work in Norway (Møller 1987) uses the altitudinal range of between 1.9 to 9.5 m above MSL (a mean of 4.8 m MSL) for nonagricultural prehistoric sites as evidence of site seasonality and interprets microstratigraphy for evidence of marine transgression. However, the use of archaeological data solely as a chronological referent limits severely the possible breadth in the beach ridge geoarchaeological method. Human settlement pattern is an intimate data point and should be scrutinized for relevant regionally specific details related to paleoclimate.

Paleoclimatology and Beach Ridges: Peru, Australia and the Netherlands

The most innovative use of the beach ridge method originates from widely separated regions: Peru and Australia. In Peru, archaeological limiting dates from gravel ridges near the Santa River allow Sandweiss (1986) to estimate the increase in sediment supply at the shore due to torrential rainfall resulting from the sea surface temperature anomaly of El Niño. Detailed stratigraphic observations within archaeological sites (Rollins et al. 1986) confirm Sandweiss' interpretation. The Peruvian example appears rather uncomplicated, consisting of only eight discrete shore-parallel ridges which clearly derive sediment from the nearby Santa River.

However, the dating of the storm-induced deposition may be questioned since only a few superimposed radiocarbon samples constrain the chronology (Sandweiss et al. 1983). Differences in ridge height of about 1.0 m are interpreted as a measure of tectonic uplift rather than storm intensity, a finding seemingly corroborated by a stranded marine scarp lying over 1 km inland dated to 5000 BP (Rollins, et al., 1986). At the Chira beach ridges in northern Peru, Richardson (1983) describes a uplifted and stranded beach ridge complex 2.7 km wide in which only nine ridges formed at irregular intervals between 4500 BP and the present. Though uplift is also the rationale offered by Richardson for differences in elevation among the Chira ridges, the actual range of ridge elevation may contradict this since *both* the youngest and oldest ridges are about 5 m in elevation with intervening ridges varying from 1 to 2.5 m above MSL (Richardson, 1983:Fig. 4). Because swale widths are thought to provide an approximation of storm recurrence intervals, the Chira ridge elevations may be better explained by differences in storm intensity. Such correlations of Peruvian beach ridge chronology should be evaluated with respect to the increasingly detailed alluvial and archaeological stratigraphy reviewed by Wells (1987) and DeVries (1987) recording increased upvalley flooding associated with El Niño events 600, 1100 and 1300-1400 and 1720 AD.

In Australia, an inter-disciplinary team of researchers has developed a detailed geoarchaeological synthesis on a beach ridge/chenier plain at Princess Charlotte Bay, Queensland (Chappell and Grindrod, 1984; Beaton, 1985). A major factor on the depositional processes at Princess Charlotte Bay involves the interplay between high magnitude storm events and the variations in the production of shell material and the clay content within the nearshore. Clay concentration is related to wet season rainfall and fire history. All these factors enter into the availability of shell at the shoreface, in that when clay deposition is low, high storm waves are able to winnow mud from shellbeds which leads to an increase in biological productivity of mollusks and crustaceans and increase the number of shells, as well as exposing more shell for re-mobilization. Consequently, chenier ridges are built when shell material is plentiful. By contrast, only beach ridges accrete during the absence or inaccessibility of shell. The record may be read as a proxy for Holocene climatic change in that conditions of heightened regional aridity result in less clay input, while more sediment is available during more stable, mesic intervals . The coarser, sandy cheniers are the result of "a series of closely spaced storms during periods of reduced fluvial input" (Lees and Clements 1987: 312)

Human occupation of the Princess Charlotte cheniers is also episodic, but dramatic stratigraphically. In a particularly well-dated section, with over 20 radiocarbon dates, Beaton (1985:8 and Fig. 2) documents a shell mound, the South Mound, constructed nearly 2 meters high from 1715±55 (β-1754) to 660±10 BP (ANU-3383). The mound is composed of only eight discrete, probably rapid, depositional events, separated by "sediment-rich" phases of abandonment. Several prominent date reversals in the South Mound show the probability of redistribution of midden material by later use and the continued use of ridges distant from the actively aggrading shoreline. The researchers (Chappell and Grindrod, 1984:222) assert that human predation is not a factor in the limiting the availability of shell for constructing chenier ridges.

The western shore of the Netherlands, north of the Rhine River, reveals a series of transgressive coastal dunes , similar in some respects to beach ridge settings. Dutch researchers (Jelgersma et al. 1970, Berendsen and Zagwijn 1984) use a wide variety of techniques and interdisciplinary approaches; ranging from pollen and pedological analyses to sedimentary facies analyses of geologic cores, archaeological excavations and historical research. The reconstructed Holocene history for the Dutch coast reveals alternations in progradation 5000-2900 BP and erosional episodes forming transgressive dunes (the Older and Younger Dunes). Minor dune activity is recorded as early as 3000 BP and continued intermittently (the Older Dunes) until the culmination of dune-building occurs in the Little Ice Age, 1400-1700 AD. Roep (1984) attributes decreases in sediment supply (from the Rhine) 2300-2000 BP, coupled with climatic or sea level fluctuations, to explain the coastal evolution.

Why "Beach Ridge Archaeology" is Needed:
Incidental Use of Archaeological Data by Geologists:

Frequently, geologists have seized upon the possibility of using archaeological sites as a chronological referent. However, this usage is typically anecdotal and often uncritical. It is worth reviewing several cases of such usage and assessing it in light of "beach ridge archaeology."

One of the landmark studies of beach ridge evolution was conducted on the west coast of Mexico by Curray et al. (1969). Though Curray's chronology is largely based on samples from drill cores, shell from archaeological middens was also used. However, these archaeological data are not assessed critically in a taphonomic sense nor in regard to cultural history. The greatest problems in accepting a single shell date from a midden involve the possibility that a lengthy human occupation may result in the mixing of discrete occupations or the possibility of accepting biased, non-representative samples of a long occupation. Geologists should be asking what is important: The earliest date of occupation? The time span of occupation? The time of abandonment? Which date is critical to answer the question being asked?

Geological researchers along the northwest coast of Florida have also used shell dates from middens in a largely uncritical manner. The beach ridge plain of St. Vincent Island contains over 200 ridges divided into twelve distinct depositional units but is dated by only five radiocarbon dates from shell middens (Demirpolat and Tanner 1987). Most of the archaeological sites on St. Vincent Island lie on the lagoon side of the island and do not adequately provide a measure of the horizontal progradation (Stapor 1975:Fig.5), for reasons discussed below.

On the prograding southern coast of Brazil, Fairbridge (1976) and his Brazilian colleagues use the paleoecology of molluscs and the archaeological record to establish five principal types of shell midden. Finding that middens occur relatively close to mollusc-favorable substrates, Fairbridge establishes relative sea level position using topographic relationships such as estuarine, mangrove, lagoon spit or platform (Pleistocene or rock). To establish sea level, Fairbridge (1976:356) argues that "if the Brazilian data are to be helpful in indicating a true relation to past sea levels, it is desirable that the key midden sites be tied closely to the crystalline basement." The hard rock nature of such surfaces minimizes bias due to compaction and such elevations above sea level theoretically provide a reliable paleo-sea level estimate. Fairbridge's approach is similar to beach ridge archaeology but the prograding spits and beach ridge plains of southern Brazil could be scrutinized for cross-correlations and paleoclimatic data.

Extending the Beach Ridge Method: The World Wide Distribution of Beach Ridges

The possibilities for using the beach ridge approach are widespread--beach ridge plains occur on all the continents, including Antarcti In a encyclopedic treatment of the world's coastlines, Bird and Schwartz (1985) report beach and/or chenier ridges in diverse places: in Europe, from the Baltic Sea, Albania and Brittany; in Africa from Sierra Leone, Nigeria to the Zambezi delta of Mozambique; in Asia from the Caspian shores of Iran, Thailand, the U.S.S.R. and in Mexico, Guyana and Australia. A similar variety of locales may be found in the photographic atlas of U. S. coasts by Shepard and Wanless (1971).

Possibilities for Beach Ridge Archaeology

Atlantic and Gulf Coasts

One of the basic postulates of the beach ridge method involves the preference of maritime populations for the resources of the open shoreface. It is this preference which led Giddings and other Arctic researchers to successfully use the beach ridge method. However, resources and preferences may differ and the situation on other coastlines may not be similar. In fact, such differences hinder the progress and potential for beach ridge archaeology on the East coast and perhaps other places as well.

Along coastlines such as northwest Florida or the Carolinas the resource base on the sheltered lagoons may be greater than on the exposed beach side. Aboriginal groups preferred the lagoons to gather the plentiful shellfish and shrimp (Larson 1980:6ff). The lagoonal shoreline remains comparatively static as the beach ridge plain accretes seaward. Consequently, human populations could possibly have remained focused on the static portion of the beach ridge plain instead of following the prograding strand.

Cape Hatteras and other settings

The Atlantic coast undergoes a radical shift in orientation at Cape Hatteras, which records at least seven depositional cycles resulting in the progradation of over 100 ridges (Fisher 1967). Despite Fisher's (1967) detailed geological mapping of the numerous beach ridges from the Outer Banks of North Carolina and the early archaeological surveys of Haag (1958) no integration of geological and archaeological data has yet been attempted. Fisher (1967: 26) did not encounter any "carbonaceous material" or datable shell and did not date grass beds. Instead, Fisher relied on pedogenic weathering horizons for tentative relative age estimates and correlations. Haag (1958) describes nine sites oriented primarily toward the lagoon and dating to early late Woodland period times (1000 BP). A major problem in using beach ridge methods seems to be the continued use of the lagoon of the island by all subsequent inhabitants (Loftfield 1988).

Several other possible sites for beach ridge studies exist on the Eastern seaboard: Cape Cod, surveyed archaeologically by the NPS in the late 1970s (McManamon 1984), Cape Canaveral, FL, the much disturbed Sandy Hook spit, at the entrance to New York bay, and Cape Henry near Norfolk, VA (Fisher 1967).

The Georgia Coast

De Pratter and Howard (1977) used prograding shore-parallel deposits at the mouth of the Savannah River to document culture history (Fig. 1.3). De Pratter and Howard's work has much in common with beach ridge archaeology, but the Savannah River deposits closely resemble a chenier system. Four principal sedimentary facies and depositional regimes are evident along the Georgia coast: (I) in areas adjacent to outlets of rivers and abundant sediment supply, coastal progradation was rapid, consisting of hammocks ("marsh islands")--eroded remnants of older beach ridges (though Oertel, 1979:279, interprets hammocks as related to overwash processes); (II) accretional recurved spits, (III) alternating phases of erosional episodes and depositional beach ridge "bundles" and (IV) straight beach ridges. De Pratter and Howard (1977:255-6) use the occurrence of temporally distinct pottery types to date the progradational sequence. Since "the sites are nearly always associated with the shells of estuarine fauna [it may be] assume[d] that the Indians chose their dwelling sites on or

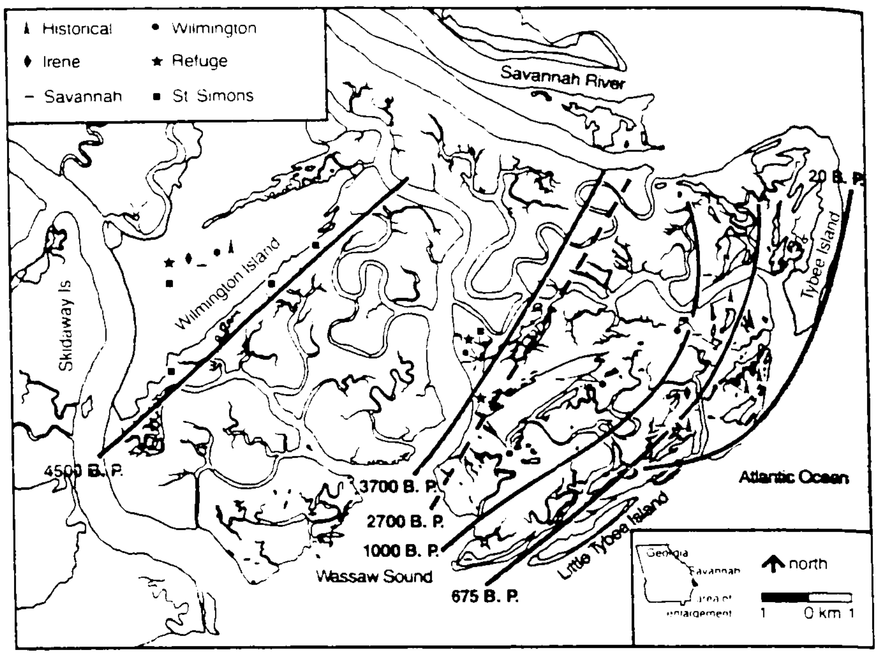


Fig. 1.3. Map of Savannah River chenier/beach ridges dated in reference to archaeological remains. From DePratter and Howard (1977).

behind the barrier ridge"...the actual shoreline would be to the east and cannot be precisely delineated due to subsequent erosion. Since younger aged sites occur considerably inland, the oldest site on a surface provides a minimum age. A further peculiarity of the Georgia barrier coast involves the inlet margin which provides the most active milieu for beach ridge development, as evident in Oertel's (1975) delineation of eighteen discrete and truncated depositional (undated) sets of ridges at the mouth of St. Catherine's Sound. Using archaeological data, Oertel (1979) has been able to sketch out a chronology for these inlet ridges.

Much of the research along the Georgia and Carolina coasts is conducted by archaeologists for the specifically archaeological purpose of building cultural chronologies. Meanwhile, geologists also work independently using cutbank exposures or the deep coring methodology, as exemplified by Moslow (1980) at Kiawah Island. On occasion, the two groups have joined to assess sea level changes (Colquhoun and Brooks 1986). De Pratter and Howard (1981, 1983) postulated a sea level fall of about 4 m 3100-2400 BP, based on the heights of middens adjacent to beach ridge complexes or by reference to dated submerged tree stumps (with elevations imprecisely known ±0.5 m MSL, but also attested by reputable nineteenth century observers). As Belknap and Hine (1983:681) note, such enterprises must consider whether middens were constructed at sea level, the effects of sediment compaction (up to 2 m), spring tidal ranges of up to 3 m and numerous other problems. The use of shell middens as sea level indicators is ill-advised since the researchers use elevation without considering the peculiarities of human discard behavior (Meehan 1972).

As of yet, no one has connected the various Atlantic coastal changes with other proxy climatic records or correlated the various localities into a unified sequence. Climatic controls may be responsible for the common histories of the cheniers of the Mississippi and the Savannah Rivers, as evidenced by rapid progradation 3-2 kya, relative stasis 2-1 kya and progradation from 1.1 kya to 650 yrs ago..

Beach Ridges on Pacific Coasts

Oregon and Washington

While East Coast researchers appreciate the possibility of combining geological with archaeological data, to date, few West Coast archaeologists seem to have integrated the two bodies of data. As an example of the unrealized possibilities, I will examine the situation on the Oregon and Washington coast.

Sand dunes and spits are very extensive along the Pacific coast of Oregon and Washington. Cooper (1958) reported on several prograding sequences located primarily at mouths of rivers and bays. A series of nine prominent beach ridges on the Clatsop prairie south of the mouth of the Columbia River. The Clatsop ridges built from north to south, away from the Columbia River, its sediment source, and are grouped into three depositional units by Cooper (1958:122ff). Sporadic archaeological surveys (conducted from the 1950's to the 1970's) in the Clatsop area record fourteen shell middens interspersed between beach ridges (Minor 1983: Figure 13.2). One site (35-CLT-27) lies about 1.2 km from the ocean within Cooper's Stage II and dates 860±100 (WSU-1454) to 730±110 BP (WSU-1455) (Sheppard and Chatters 1976:145). Depositional Stage II is characterized by decreased progradation near the river mouth but increased progradation in the south. Perhaps with further research, Quaternary scientists will be able to establish the "obscure, perhaps undiscoverable causes" underlying the facts that Cooper observed (1958:125). As yet however, no attempt has been made to integrate the archaeological with geological data.[3] A similar setting and potential for beach ridge archaeology is located north of the Columbia River at Grays Harbor and Willapa Bay; extensive beach ridge spits form the mouths of these estuaries.

Gulf of California

An interesting possibility of relating beach ridge with inland geomorphic changes is available from the Colorado River delta. Within a normally tidal mud flat depositional regime, occasionally coarser grained beach ridges form due to wave processes and longshore currents. Beach ridges formed 3000-2000 BP and from 1200-700 BP (Thompson 1968: 112ff) and are related to the diversion of the Colorado River into Salton basin which created Lake Cahuilla, starving the nearshore system of finer sediments. Though no archaeological remains are reported from the Gulf of California ridges, the shores of Lake Cahuilla are rich in archaeological sites (Waters 1983). Four lacustral intervals are noted at Lake Cahuila in the last 2000 yrs, with high stands

3 An interesting relationship may be to increased flooding upstream on the Columbia River reported by Chatters and Hoover (1986) ca. 1200-700 B.P., attributed to climatic warming.

falling 700-1580 AD. The lake did not exist from 2000-1300 BP--during the time of mudflat progradation on the Colorado.

China and South East Asia

Pronounced shifts in lateral shore position are recorded by researchers in China, Vietnam and Thailand during the middle and late Holocene. The present body of data derives primarily from an extensive series of cores, radiocarbon dates on macrofossils (Geyh et al. 1981) and marine mollusca biofacies.

Evidence for a middle Holocene marine transgression is reported in both Vietnam and Thailand using a geoarchaeological approach similar to that of the beach ridge method. At the Khok Phanom Di site, Thailand, now 22 km inland from the Gulf of Thailand, marine clays and brackish water plant pollen indicate that the site was probably on a coastal barrier island at 6700-6000 BP (Higham 1989:66). Excavating on "raised beaches" Vietnamese researchers in the Red River valley region near Hanoi observe shellfish middens of middle and late Neolithic age, 4000 BP (reviewed in Jamieson 1981) Once again, eustatic sea levels are thought to have been 3 m higher at this time of occupation. An explicitly geoarchaeological approach would help to clarify the interwoven effects of deltaic processes, eustatic changes and storm effects.

Research in north China indicates that the sea transgressed up to 100 km inland 6000-5000 BP and rose over 2-4 m above modern levels (Ota 1987). A series of chenier ridges record the subsequent decline in sea level. Using ^{14}C and historic documents, Liu and Walker (1989) describe a series of four principal chenier ridges on the north China plain. So far, no archaeological sites are linked with the sequence. Though in a recent revision of Chinese prehistory, Chang (1986:72ff) acknowledges the paleogeographic effects, the possibilities of documenting cultural chronology and coastal evolution are yet to be realized in China.

Core-derived Coastal Reconstructions vs. Beach Ridge Archaeology

The beach ridge method is not the only methodology employed to reconstruct the outlines of paleoshorelines. In fact, the traditional geological practice of extracting cores is probably more extensively employed in the field. A comparison of the beach ridge method with that of deep coring reveals that while more detailed, less equivocal, stratigraphic data may be obtained with cores, the beach ridge method may be more expeditious and provide more contextual evidence for human occupation. Perhaps, the ideal approach would combine the two methods.

Along the exposed Delaware coast erosion predominates (Dubois 1988). However, the excess of eroded sediment is transported north and results in progradation at the entrance to Delaware Bay, at the Cape Henlopen spit (Kraft 1971). Kraft and his co-workers (1979) reconstruct paleoeshores for the Holocene with surprising exactitude. These reconstructions derive from interpretations of sedimentary facies within cores and provide a general picture of coastal evolution rather than a specific topography (Kraft 1971). In one instance, 2000 BP, Kraft and John (1976) do integrate several Woodland period sites within the paleospit at Cape Henlopen, but over all, site specific context within the spit is subsumed in their generalized reconstructions of coastal evolution.

Conclusions

The history of science often records the parallel efforts of widely separated, often isolated researchers who independently discover a new technique or observe the same phenomena. The quantification of coastal evolution using archaeological sites is another striking example of such independent invention. Though Louis Giddings believed his "beach ridge archaeology" offered a radically new method, the method had already been invented--twice, first in England and then in Louisiana. In the nineteenth century, British historians used stranded villages to reconstruct the course of coastal evolution at Dungeness Foreland. Similarly, geologists working in the Mississippi delta inferred delta lobe abandonment based on archaeological sites.

One of the earliest recognized utilities of progading coastal sedimentary facies involved the construction of cultural chronologies. Investigators in Alaska, as well as Mississippi and Vietnam, use the horizontal placement of sites to establish cultural continuity. The survey methodology of "beach ridge dating" requires an adequate ethnographic basis and can yet can ultimately suffer from the circular reasoning implicit in ethnographic analogy. As can be seen along the Gulf Coast, the facile use of horizontal location must be tempered with cultural ecological factors such as resource use and discard behavior. Though the usage of relative beach ridge position provides a survey methodology, this usage does not exhaust the potential implications of the beach ridge method.

In studies of shoreline evolution, archaeological sites are routinely used like any other chronological reference point, as a source of radiocarbon datable material. Geologists and archaeologists must consider the idiosyncratic factors associated with human settlements before using midden or settlement elevations as sea level indicators. In this regard, human settlements can provide a microfaunal, site specific description of coastal depositional environments. Reconstructions of paleoshoreline and sea levels are common research goals of beach ridge studies and the more commonly used deep coring methodology.

Once again, geologists must expand their vision beyond the esoterica of facies relations and problems to include the climatic implications of widespread records of progradation or erosion. There is a serious need for wide scale correlation studies of barrier island/beach ridge complexes along the Atlantic seaboard and in the Pacific Northwest. Such extended records could provide a proxy record of late Holocene paleo-climate. Studies of shoreline evolution can also focus on the interrelations between depositional environment and regional climatic parameters. A fertile area for study involves the relationship between upriver regions of sediment supply and coastal environments of storage and deposition--as in the cases of Peru, Australia, and the Mississippi, Columbia and Colorado Rivers cited above. Observations about the orientation of discrete ridge units or truncations in ridge deposition have led to reconstructions of regional climate in Mexico and Alaska.

A new approach among researchers involves the wider scope of problems including CO_2 induced warming and El Niño phenomena, as in Peru. The trend of seeking supra-regional linkages to explain beach ridge patterns offers the greatest potential but requires a comprehensive interdisciplinary approach, as a cross check. While a single technique provides one type of evidence, the results from two diverse fields may yield more ambiguous results. Consideration must be given to the the range of variation in phenomena, ie., as in Peru, where the temperature tolerance of intertidal species must be established *before* correlations of sea surface temperature with archaeofaunas can be made. As evident by the interdisciplinary review of DeVries (1987), the principal hurtles in interpretation are the simplistic uses of modern analogy, imprecise dating of deposits and the facile inferences based on paleontological samples.

Chapter 2

Dynamics and History of the Cape Espenberg Beach Ridge Plain

Introduction

The shifting longshore trajectories and temporary storage of sand provide geologists with numerous inferences about transient and long-term climatic changes. Prograding coastal deposits such as beach ridge plains and spits reflect particular climatically induced circumstances in the nearshore zone. Researchers use such prograding settings to infer shifts in wind direction (Moore and Giddings 1961, Curray et al. 1969), Holocene storm periodicities (Fairbridge and Hilliare 1977), the intensity of El Niño (Sandweiss 1986) and to construct alluvial histories (Gould and McFarlan 1959, De Pratter and Howard 1977). In this study, I examine the development of the Cape Espenberg spit of northern Seward Peninsula during the late Holocene in relation to shifts in wind intensity and other climatic variables.

The study of coastal sedimentary deposits such as dunes and beach ridges often has great immediacy in areas subject to intense erosion. Though dunes can generally protect settlements from erosive waves, transgressive coastal dunes buried several settlements along the North Sea coast in the Middle Ages (Lamb 1988). The efforts of Dutch researchers (Jelsgerma et al. 1970) include an interdisciplinary approach--using sedimentary structures, pedology, archaeology, and palynology--to provide detailed records of past climates, vegetation, and human adaptations. In defining sedimentary facies in dunes in relation to sea surface indicators, Roep (1986) provides a means of inferring sea level changes. In light of modern concerns with CO_2 induced global warming and its effect on sea levels, the history of coastal environments is extremely relevant.

Despite the volume of scholarly studies on the sedimentology and facies relations of spits and beach ridges (Reinson 1984), comparatively few studies concern their Holocene history or cross-correlations. When geologists study sedimentary deposits they are particularly concerned with "hard-rock" geological models. In the last twenty years, the emerging interdisciplinary synthesis of Quaternary Studies has focused more interest on recent, unlithified sediments with the goal of paleoclimatic and paleoenvironmental reconstructions.

A major difficulty in undertaking chronological studies of coastal deposits involves the recovery of datable materials. As Fisher (1967) reported from the Outer Banks of North Carolina, carbonaceous material is often rare in sand ridges, especially in older ridges where most shell may have dissolved. An interdisciplinary approach aids in overcoming this problem. In northwest Alaska, several generations of researchers have meshed geological and archaeological methods. The use of archaeological radiocarbon assays allows the dating of individual depositional units and the cross-correlation of several complexes. The Cape Espenberg spit, located in northwest Alaska (Figs. 2.1, 2.2), is a particularly unique geomorphic feature, combining aspects of a beach ridge plain and a recurved baymouth spit. The spit has this character from its location at the northern extreme of Seward Peninsula at the terminus of a northeasterly longshore transport system and at the entrance to Kotzebue Sound.

Research Aims

I undertook the research described here for three purposes:

(1) to describe the formation processes of beach ridges and dunes, as reflected in sedimentary structures and grain size parameters;

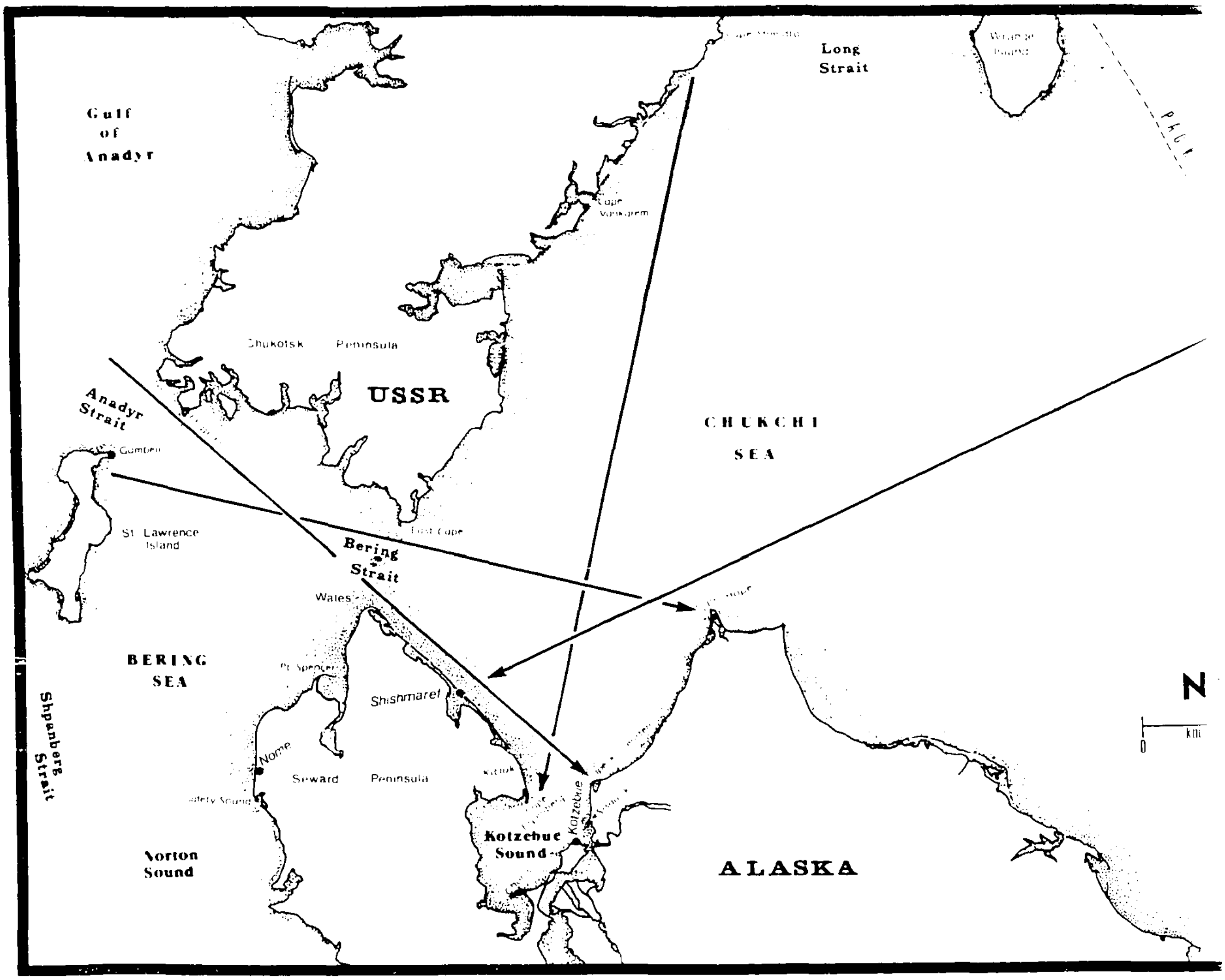
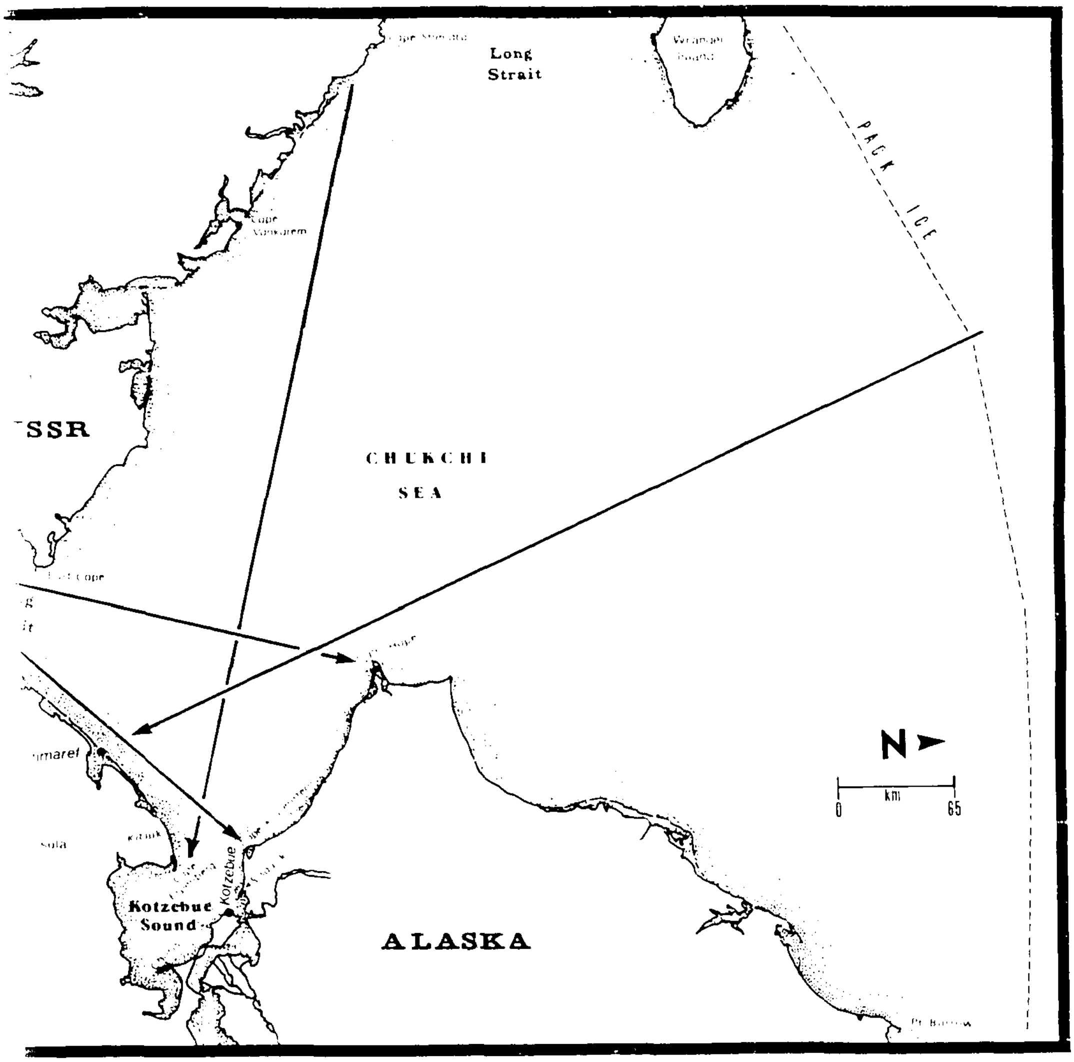


Fig. 2.1. Map of Chukchi Sea indicating the greatest fetch distances (dark lines with arrows, cf. Table I for distances. Major beach ridge plains are indicated at coastal inflections. Towns marked by circles (•). Pack ice, marked by dashed line, is the summer maximum open water value–the entire Chukchi Sea is frozen in winter.



Chukchi Sea indicating the greatest fetch distances (dark
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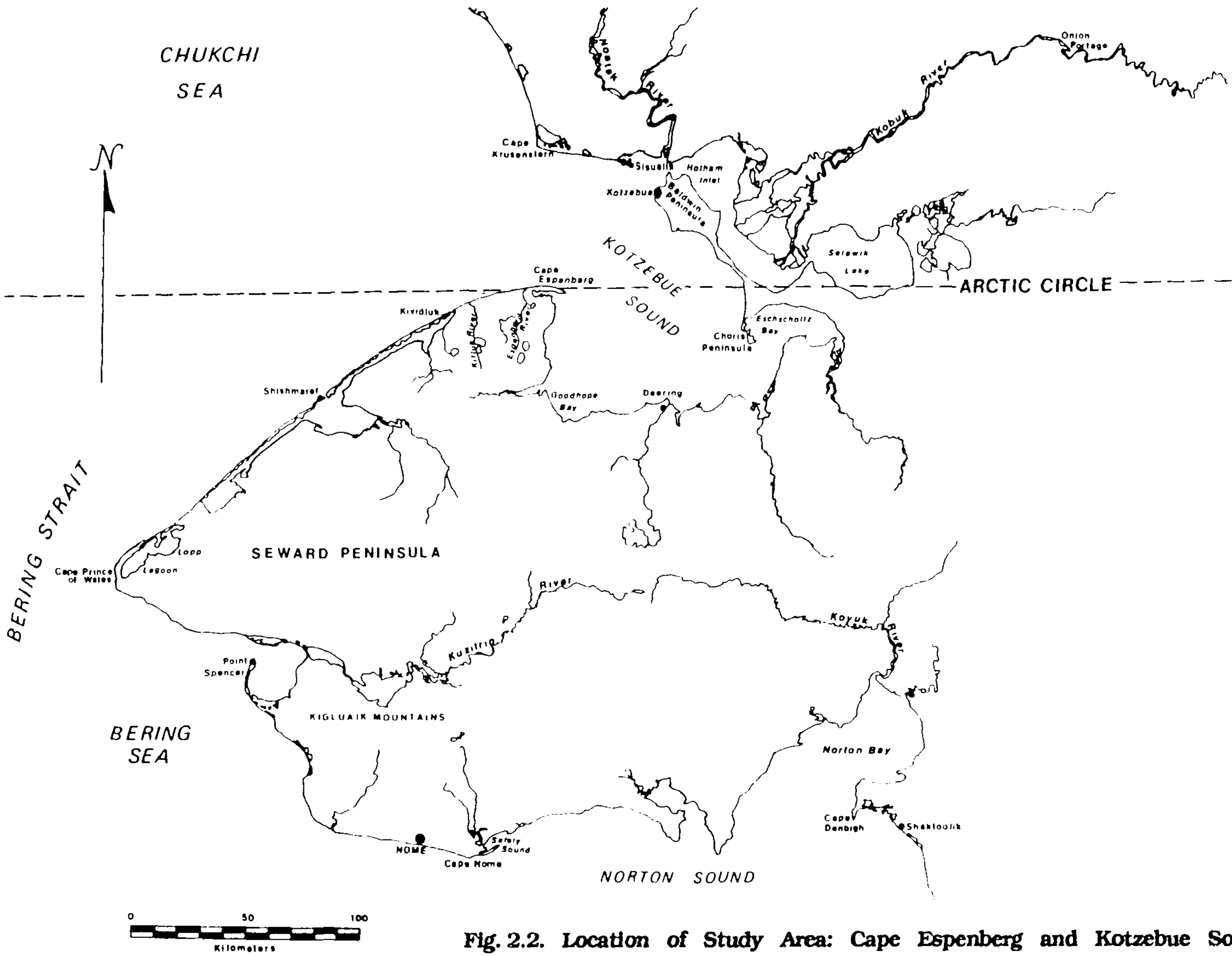

Fig. 2.2. Location of Study Area: Cape Espenberg and Kotzebue Sound

(2) to examine the topographic evolution of the Espenberg ridges through the late Holocene;
(3) to relate these processes to climatic and oceanographic parameters.

Beach Ridges and Coastal Dunes in Northwest Alaska

In northwest Alaska, beach ridge plains occur at seven inflections in coastal orientation between Bering Strait to Point Hope (Fig. 2.1) (Mason this volume, Ch. 5). The geomorphic character of a particular beach ridge complex is determined largely by the grain size and lithology available offshore and updrift. The southeast Chukchi Sea coast is divided into two lithic regions: (1) sandy beaches along the north Seward Peninsula coast and at Sisualik near the mouth of the Noatak River and (2) gravel beaches along the remainder of the coast from southern Kotzebue Sound to Point Hope.

The area examined in this study is the Cape Espenberg spit, located at the northern extreme of the Seward Peninsula, straddling the Arctic Circle (Fig. 2.2). The Cape Espenberg spit extends for about 30 km west to east and varies in width from 1 to 2 km.

On the sandy coasts of Seward Peninsula, beach ridges are often ornamented with dunes. Thus, investigations into the history of progradation involve several steps: distinguishing differing modes of formation (marine versus eolian), interpreting the complex internal stratigraphy of the dunes: describing primary structures, paleosols and cryogenic alterations; and, finally, analyzing the dissection of the beach ridge due to biological factors (Mason this volume, ch. 3).

Arctic coastal dunes reflect cryogenic conditions that deform beds and other syngenetic modifications. Ice and sand wedge structures are widely reported in Canada, the U.S.S.R. and Alaska and a voluminous literature exists on the subject. Convolutions, de-watering and denivation structures occur frequently under permafrost conditions and studies of Arctic dunes (Koster and Dijkmans 1988) show commonalities with dunes in modern alpine environments and paleoenvironments (Steidtman 1973, Ahlbrandt and Andrews 1978).

The construction of a beach ridge plain requires several pre-conditions: low tidal fluctuations, a local surplus of sediment, a tectonically stable shoreline and quasi-stable sea-levels (Curray 1964, Hayes 1979). To provide background for the evolution of the Espenberg beach ridge plain, I offer the following preface: first, a consideration of wave climate and meteorology, then a discussion of sea level history and tectonics and, finally, data on sediment sources.

Wave Climate and Meteorology of the Chukchi Sea

The Chukchi Sea is a rectangular embayment of the Arctic Ocean formed by the shores of northwest Alaska (U.S.A.) and northeast Chukotka (U.S.S.R.) (Fig. 2.1). The sea lies north of Bering Strait, 65° N. lat., and extends to the seasonally fluctuating limit of Arctic pack ice at 71° to 75° N. lat. The Chukchi Sea is microtidal, probably less than one meter in range. At Shishmaref, on the south shore of the Chukchi, the tides show an estimated range of up to 0.76 m with the highest tidal debris at 0.975 m above MSL,[1] according to Peratrovich and Nottingham (1982:7). At Espenberg, storm-deposited drift debris is found up to 2.25 m above MSL (Mason 1988, field notes). Ice covers the entire Chukchi Sea during the winter months, leaving only the annually variable 4 to 5 month period from June to October subject to open water oceanic processes (LaBelle et al. 1983).

Maximum fetch in the Chukchi Sea is northwest/southeast (Fig. 2.1). Wind fetch is an important variable because potential wave height increases with fetch (Komar 1976). As can be seen in Table I, fetch distances vary considerably from only about 190 km west to east at Shishmaref to as much as 1125 km from the northwest or north to south during conditions of summer maximum open water from Wrangel Island to Shishmaref. Following the trend of the Seward Peninsula to the northeast, the Chukchi Sea north shore shelters Kotzebue Sound from northerly winds (Fig. 2.1). Hence, the extent of available fetch drops drastically from the 1125 km north/south maximum at Shishmaref to less than 250 km northeast of the Kitluk River, about 20 km west of the Espenberg spit. This decrease in available fetch across the Chukchi Sea means that the Espenberg spit lies within a region sheltered, to some degree, from intense storm waves from due North.

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[1] For this study Mean Sea Level (MSL) refers to mean low water because tidal fluctuations are so insignficant. Field observations were made during summers of 1986-88. No gauge data is available for this region.

The passage of weather systems governs the wave climate capable of effecting the nearshore and shoreface (Fox and Davis 1976, Kowalik 1984). At present, based on the limited (40 yrs) instrument data available, major storms frequently enter the Chukchi Sea from the southwest by way of the Bering Strait. High intensity storms are most common during fall--especially in September and October (Wise et al. 1981). Depending on the path and duration of an individual storm system, the associated winds will generate waves from various directions (Hume and Schalk 1967, Kowalik 1984). In the initial phase of storm entry, winds from the southwest may generate large waves toward the northern shore of Kotzebue Sound at Cape Krusenstern and also at Point Hope. In later phases, winds may shift to the west, northwest or north quadrants.

Southerly winds associated with several autumn storms in 1973-74 produced storm surge conditions as sea level rose along the Seward Peninsula coasts, with 5 m high waves at Shishmaref (Fathauer 1975, Wise et al. 1981:11ff). With a fetch of only 150 km available from the west, Peratrovich and Nottingham (1982:9) calculate that low level 0.37 m storm surges at Shishmaref have a recurrence interval of 50 yrs. J.W. Jordan (1990) estimates that higher surges of 1 to 2 m occur once every ten years, using post-storm beach profile data, available records and wind data from East Cape, Siberia.

In microtidal regions, water surface changes due to atmospheric pressure differentials alone can be quite significant, with a range of up to 40 cm recorded offshore (Hunkins 1965) and over 1 m in a single day at Pt. Barrow (Hume and Schalk 1967, Matthews 1970).

Currents

The deposition of sediment in the nearshore zone is influenced by the identity, strength and speed of water masses and currents. The principal water mass affecting the Seward Peninsula coast is the Alaskan Coastal Water which enters the Chukchi Sea from Bering Strait, flows to the north about 60-80 km and then either continues following the coast northwest toward Pt. Hope or diverges northeast into Kotzebue Sound--at an annually variable amount. The swiftest upper layer flows of 150 cm sec^{-1} are encountered in the eastern channel of Bering Strait, decreasing to speeds of about 50 cm sec^{1} in the central Chukchi Sea, with a further marked deceleration to 15-20 cm sec^{-1} at the entrance to Kotzebue Sound (Coachman et al. 1975:140). As a result of the current divergence to the northwest, a small clockwise gyre forms near Cape Espenberg. With a "reduction in current speed, the sediments rapidly settle out, depositing a spit (Cape Espenberg) and a chain of islands to the south" (Sharma 1979:404).

Near bottom currents (within 3 m) are 30 to 35 cm/sec in the Bering Strait and northeast along Seward Peninsula. These currents are swift enough to transport clay, silt and fine sand into and across the southeastern Chukchi Sea (McManus et al. 1969).

Surface pressure and winds strongly influence the development of nearshore coastal currents. Wind speed accounts for about 66% of the variability of the flow through the Bering Strait (Aagaard et al. 1985:7215). Strong northerly winds lasting for several days can reverse the predominant flow regime in the Strait, due to a set-down of sea level in Norton Sound. As described above, winds from the west, north or northwest prevail across the Chukchi Sea (La Belle et al. 1983). During periods dominated by high pressure or lacking high intensity storms, such low winds ($\leq$4.47m/sec) produce a northeast setting longshore current. Such a current regime has prevailed during the last 80 yrs, according to the oldest informants at Shishmaref (Gideon Barr in J.W. Jordan, unpublished notes, 1988).

Tides at Espenberg are mixed and are reported in reference to the Kodiak station. The principal tidal wave (M_2) affecting the Chukchi Sea originates from the North Atlantic sector. Upon reaching the enclosed Chukchi Sea, the Atlantic tidal wave encounters a smaller tidal wave entering from the Pacific (Kowalik and Matthews 1982). This interaction produces an amphidromic point, a rotary anti-clockwise motion of the tidal wave focused on a single point; in this case, southwest of Pt. Hope.

To summarize, then, the Cape Espenberg region lies at the entrance of the sheltered embayment of Kotzebue Sound at the terminus of the longshore transport system. Cape Espenberg is semi-sheltered from northerly fetch and is subject to coastal currents with decelerating flow at the entry of tidal currents into Kotzebue Sound. The combination of these factors leads to a net progradational setting in the Espenberg region.

Since longshore sediment movement is tied to the effects of onshore winds (Moore 1966, Komar 1976), Moore and Giddings (1961) linked the development of beach ridge/barrier complexes to variations in prevailing wind direction throughout the late Holocene. Since progadation can occur in conjunction with rising sea levels only if the supply of sediment keeps pace (Curray 1964), the longterm trend of sea level rise is important. Rapid eustatic sea level rise during the early Holocene (ca. 10-6 kyr) probably submerged any shoreface deposits until the comparative stabilization of sea levels after 4000 BP in the Chukchi Sea. "Degraded barriers" or shoreface retreat blankets (*sensu* Swift et al. 1973, Swift 1975) may lie within offshore sand deposits. To consider this possibility, we need examine the sea level history of the Chukchi Sea.

Sea Level History in the Chukchi Sea

The Chukchi Sea, less than 80 m deep, was subaerially exposed as part of the Beringian subcontinent during the late Pleistocene glaciations. The Holocene transgression of the Chukchi shelf began after 15,500 BP with the flooding of Bering Strait (McManus et al. 1983), though earlier marine incursions had occurred from the northerly Arctic Ocean. Sea level rose at an approximate rate of 6 m/1000 years, reaching about -30 m at 12,000 BP At this time, Shpanberg and Anadyr Straits were flooded resulting in the establishment of nearly modern oceanic circulation (McManus and Creager 1984). After 12,000 BP, sea level rise slowed considerably, asymptotically approaching near modern sea levels around 5000 years ago. Evidence of early Holocene still stands derives from imprecisely dated topographic submarine features. At 10,000 BP sea level in the adjacent Bering Sea stood at about -20 m after which the shallow Norton Sound basin was flooded (C. Nelson 1982). A pronounced submarine scarp at -6 to -7 m in southern Kotzebue Sound (Hunter and Reiss 1985) may mark a stillstand at some time between 9000 and 5000 BP, as may shore-parallel linear ridges south of Bering Strait, near Pt. Spencer (C. Nelson 1982).

The basis for inferences on sea level changes derives from a series of offshore cores and the interpretation of benthic foraminiferal faunas (McManus et al. 1983). Coring in waters 30-70 m deep, with low annual sediment accumulations and insufficient datable carbon, oceanographers do not record finer scale sea level changes after 5000 BP. To document late Holocene sea level history we must rely, at present, on the surficial terrestrial record and its superimposed archaeological remains. The formation of beach ridges in Kotzebue Sound began only after 4000 BP and provides an upper limiting date on the establishment of near modern sea level, as suggested by Moore (1961) and Hopkins (1967, 1973). A gravel deposit that transgresses dated terrestrial peats near Pt. Barrow may provide evidence of sea level stabilization about 3000 yrs ago (Brown and Sellmann 1966).

Short-term eustatic sea level fluctuations may be responsible for higher ridges dated 2000-900 BP at Point Hope, Cape Krusenstern (Moore 1960) and at Point Barrow (Hume 1965). However, possibly sea levels were only temporarily elevated due to low barometric pressure associated with storms which resulted in the deposition of high beach ridges. However, because beach ridge complexes have prograded at nearly all the critical headlands of the Chukchi Sea, I assume that sea level has been nearly constant (within 1-2 meters of present) during the late Holocene, ca. 2500 BP to the present.

Tectonic Setting

Kotzebue Sound and Seward Peninsula lie within a moderately active seismogenic province connected to the Brooks Range within a zone "characterized by a relatively thin crust, scattered Quaternary volcanism [and] relatively high heat flow....[in a] regime of extensional tectonics" (Thenhaus et al. 1982:7). The northern Seward Peninsula coastal plain and Kotzebue Sound are the surface expression of a subsiding basin comprised of Cenozoic sediments several thousand meters thick. The sediments are crosscut by several east/west faults just south of Cape Espenberg which are splays of the Kobuk system (Hopkins 1988). Little vertical motion has been observed during the Holocene, the time scale of this study. To the north of Espenberg, high resolution reflection studies show an absence of Holocene activity on faults covered by transgressive marine deposits on the submarine Kotzebue Ridge, in the Chukchi Sea north of Seward Peninsula (Eittreim et al. 1977). In light of this quiescence, the shores of Kotzebue Sound may be regarded as tectonically stable for the period of this study.

Source of Sediments:

Geology of the Chukchi Sea and its Southern Shore

To understand the formation of the beach ridge complex at Cape Espenberg spit, it is necessary to consider the sediments available for transport and their susceptibility to deposition. The fine sand at Espenberg derives from two principal sources; one terrestrial, the other marine.

The southeast shore of the Chukchi Sea is formed by the northwest Seward Peninsula coastal plain, a low-lying area mantled by eolian silty sands. Permafrost-dominated, the lowlands have been subject to several cycles of thaw lake formation during the Pleistocene and Holocene (Sainsbury 1967, Hopkins 1988, Hopkins and Kidd 1988). Little sediment enters the Chukchi Sea from the small rivers draining the north slope of the Seward Peninsula due to low sediment concentrations and discharges, as noted by Creager and McManus (1966). A significant amount of dark basaltic tephra from the interior Seward Peninsula maar lakes (Hopkins 1988) does reach beaches downdrift from the Kitluk River and other small rivers. The tephraeous sands are ubiquitious along the 20 km long coastal bluffs from the Kividluk Inlet to the west edge of Espenberg (Fig. 2.2). Such maar derived sands are not found on the Shishmaref Inlet barrier islands--to the southwest--and record the direction of prevailing longshore drift to the northeast.

Offshore, the southern Chukchi Sea floor is covered by medium to fine sand, silt, and clay, with mean size between 2ø and 3ø in diameter (Fig. 2.3) (Creager and McManus 1966). Finer silts and clays enter central Kotzebue Sound either from the Noatak and Kobuk Rivers or from the Yukon River (Naidu and Mowatt 1983). Very fine and fine sand (2 to 4ø) mantles the entire shelf adjacent to the Seward Peninsula (Creager and McManus 1966). The Chukchi shelf sands derive from at least three sources, based on mineralogical differences: (a) south coast Seward Peninsula, (b) Siberian bluffs and (c) Yukon river sands (McManus et al. 1977). A massive sand shoal extends northeast of Cape Prince of Wales (Fig. 2.3). The Wales shoal forms as coarse silt (4-5ø) and fine sand is deposited by decelerating northward currents entering the Chukchi Sea from Bering Strait (McManus et al. 1969). This offshore sand body is the principal source of sand constructing the Shishmaref Inlet barrier islands and, presumably, also for the Cape Espenberg spit, as my preliminary sediment budget shows (see below). Though the predominant direction of littoral drift is to the northeast (Creager and McManus 1966), sediment seems to be moving predominantly onshore, ie. southerly, since grain size coarsens upcoast (Mason 1987 and unpublished data) in accord with the prevailing mean grain size offshore (Creager and McManus 1966).

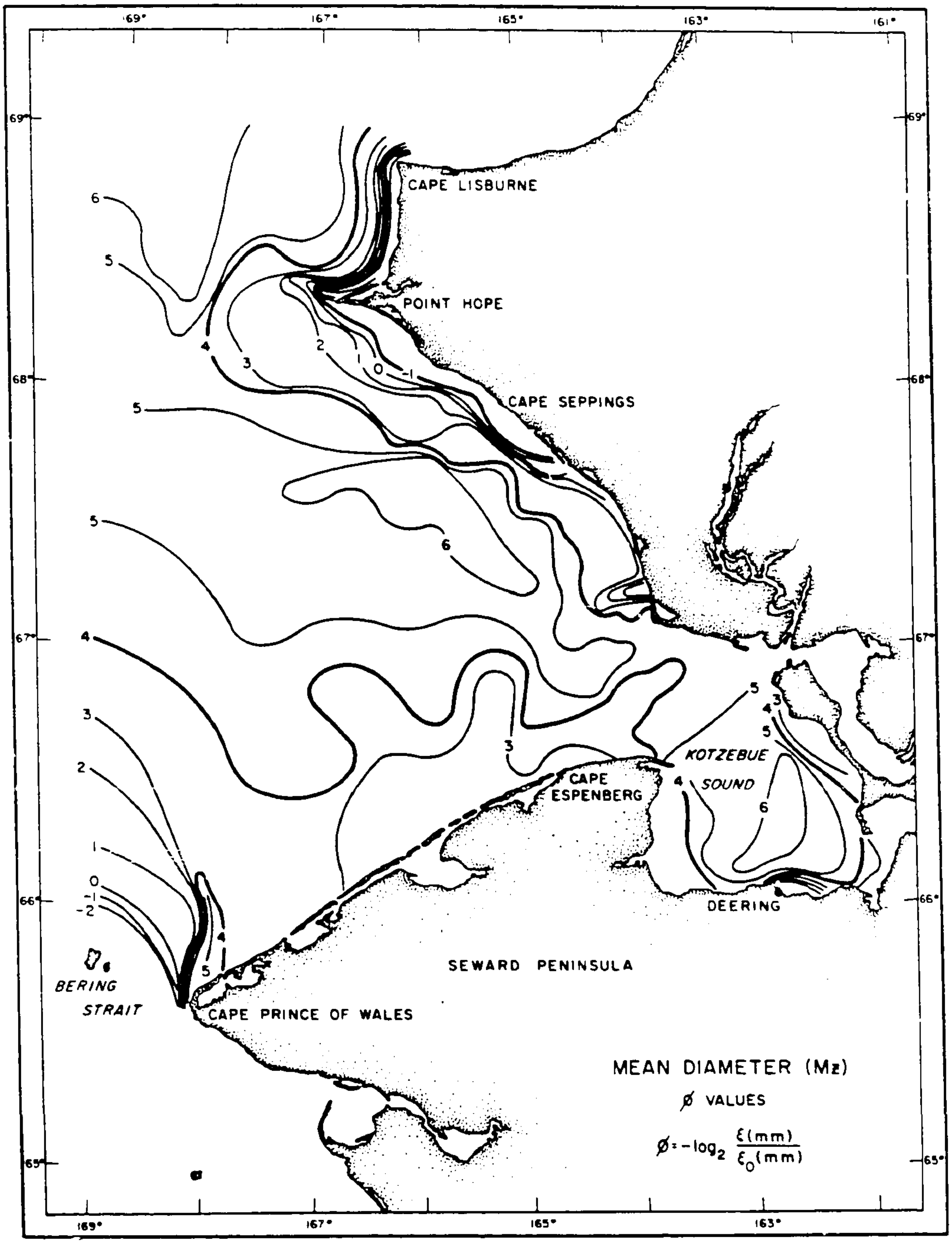

Fig. 2.3. Map showing grain size of shelf sediments in Chukchi Sea and Kotzebue Sound. (From: Creager and McManus 1966).

The origin of the sand body offshore from the Seward Peninsula is not known with certainty. The sands are either a marine re-mobilized, now-flooded terrestrial dune field, dating to the Pleistocene, or a palimpsest of former barrier islands produced as sea levels rose (Shepard and Wanless 1971:47). Some geologists argue that the Prince of Wales shoal is Holocene in age, dating after 5000 BP, and consisting of sediment transported from the Yukon River by intense currents through the Bering Strait (Nelson and Creager 1977). McManus et al. (1969) argue that most of the sand deposition must have occurred at lower than modern sea level--before 4000 BP. To date, no oceanographic data exists to substantiate these chronological interpretations. Due to the large reservoir of offshore sands in waters less than 20 m deep, the Seward Peninsula coast is characterized by energy dissipative, planar, beach profiles common on sandy coasts (Wright et al. 1979, Short and Hesp 1982). Such flat beach faces damp the energy of storm waves but allow greater landward penetration of waves (Leatherman and Zaremba 1987). The development of foredunes, washover deposits and transgressive dunes is favored within sandy materials (Ritchie and Penland 1988). The translation of sediments onshore confuses the simple correspondence between linear ridges and former shore position.

Offshore Physiography and Sand Bodies adjacent Cape Espenberg

Cape Espenberg lies at the southern entrance to Kotzebue Sound, a shallow embayment of the Chukchi Sea. The floor of Kotzebue Sound is a gently sloping plain at the 20 m bathymetric contour. The shallow Hope submarine valley originates just northeast of Espenberg and opens to the northwest. A series of shore-parallel sand bars lie 1.0-1.4 km seaward to the north of Cape Espenberg, as documented by side-scanning sonar and high resolution sesmic reflection data (Hunter and Reiss 1985) and evident in the nearshore on aerial photos by trains of breaking waves. The side-scan data indicate the longshore bars follow a gentle slope with a transition from fine grained sand to mud below the depth of about 13 m (Hunter and Reiss 1985:102).

The character and chronology of the marine deposits is outside the scope of my study, which is limited to the terrestrial record. However, the development of terrestrial beach ridge deposits requires the formation of a subaqueous spit platform (Friedman and Sanders 1978:311), which may form nearly contemporaneously with the surficial ridges. Both spit and spit platform are tied to similar coastwise longshore or onshore transport processes. The entire spit resembles an iceberg with a substantial part of the sediment body lying subsurface--the spit platform. In this study, I possess no subsurface core data for Espenberg and cannot provide any stratigraphic or chronologic details on the evolution of the Espenberg spit platform, except to note that it must have preceded the addition of the terrestrial ridges by an undetermined age.

The process of spit platform formation is ongoing, as evident from several shoals east of Cape Espenberg, observeable at low tide (Fig. 2.4). The shoals could also be eroding relict (pre-Holocene?) platform deposits. If these shoals are spit platform deposits, then the Espenberg spit is growing in a time transgressive, stepwise fashion, with deposits increasing in age west to east.

The development of the Espenberg spit partially follows the theoretical construct of Davis (1896) for Cape Cod, in which an eroding headland provides the sediment for a recurved spit. As the bluffs erode, shifts in the axis of the shoreline updrift lead to differences in the orientation in downdrift portions of the spit. Fluctuations in sediment supply may influence the configuration of the spit, as at Cape Cod (Ziegler et al. 1965). For Espenberg, as explained below, sediments from the updrift Kitluk River bluffs and tephras from the inland drainage provide some of the source materials to construct the spit.

Climatic Forcing of Progradation at Cape Espenberg: Eustatic Sea Level, Storminess and/or Sediment Supply?

In order to explain the development of the Espenberg spit, the relative importance of variations in sea level, sediment supply and/or storminess must be considered. The basic requirement for progradation is a surplus of sediment. Not only is a sediment surplus necessary; another condition must also be met: that of minimal sea level changes, whether eustatic or tidal. High magnitude sea level changes of either type re-distribute sediment offshore because an erosive regime prodominates in the nearshore environment. As the shoreline maintains an equilibrium profile over time, heightened erosion produces a slope adjustment by transferring sand offshore (Bruun 1962). A similar result arises if the nearshore system is sediment starved or if storm levels are only temporarily elevated due to barometric processes (ie. low air pressure) (Nieroda and Swift 1981, Vincent 1986).

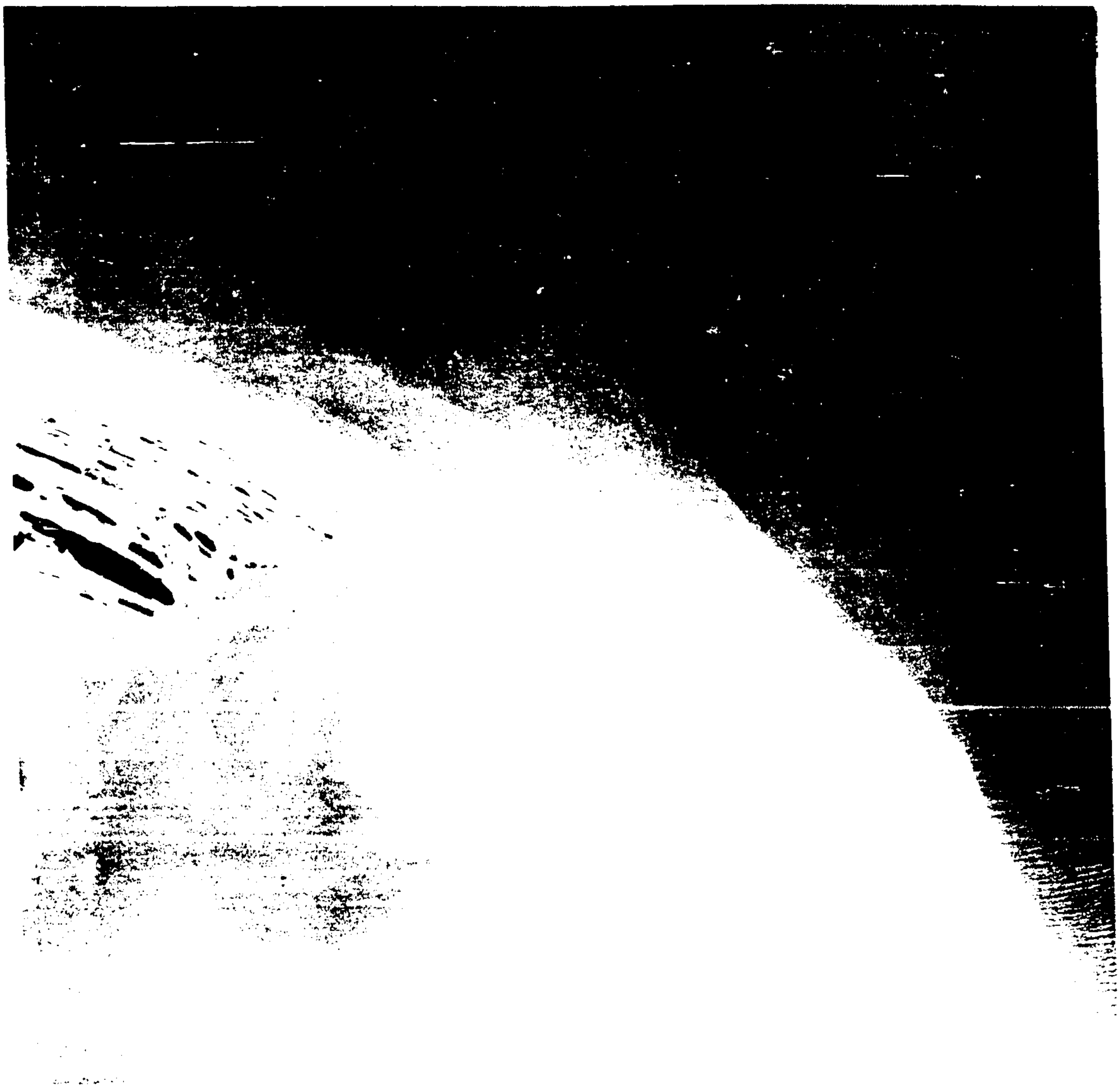

Fig. 2.4. Aerial Photograph of shoals east of Cape Espenberg. The shoals are either exhumed pre-Holocene barrier or spit deposits or, more likely, are presently forming spit platform deposits.

Eustatic sea level in northwest Alaska remained below modern levels until the onset of beach ridge progradation at about 4000 BP. If eustatic sea level changes operated as a controlling variable on coastal evolution in the last 4000 yrs, we should expect evidence of transgression--ie., eroded, re-depositional settings, as in the case of the Netherlands (van Stratten 1965, Roep 1984). Lacking subsurface data, I rely on a limited number of cutbank exposures. To find stratigraphic evidence of an eustatically driven transgression, shell-rich or coarser beach sands should occur at a consistently higher than modern sea level, applying Roep's (1986) criteria and as Searle and Woods (1983) show for western Australia. However, as I describe below, beach facies at Espenberg are found only below dune facies at *variable* heights 1.0-1.5 m above MSL. It is proposed that the occasionally higher gravel beach ridges in northwest Alaska are evidence for elevated eustatic sea level (Moore 1960, Hume 1965). However, cyclonic storms also lower air pressure and, as a consequence, sea level rises. Thus, I interprete both elevated beach facies and high gravel ridges as evidence for *temporary* increases in sea levels which are not eustatic in origin--that is, not forced by ice volume effects. Hence, lacking better documentation for long-term eustatic changes in Kotzebue Sound, I explain topographic variations in ridges as storm-driven changes in sea level.

Several researchers in Australia argue that the early Holocene eustatic sea level rise was the major agent in producing *transgressive* coastal dune fields (Pye 1984, Pye and Bowman 1984). In this view, sea level fluctuations are a "forcing variable" leading to shoreface erosion, the destruction of foredune vegetation and the initiation of blowouts. Pye and his co-workers, however, do not attribute late Holocene dune growth to eustatic factors alone, and allow that storm intensity may have varied through time. Because short-term fluctuations, e.g., atmospheric pressure and storm surge, produce high magnitude sea level changes (0.5 to 5 m), it is nearly impossible to sort out the small component (perhaps 1 mm/yr) of eustatic component of sea level rise without accurate gauge data (cf. Christiansen et al. 1985).

To explain the history of progradation in the Cape Espenberg plain, changes in sediment supply must also be considered. Espenberg sand derives from the two sources cited above: offshore marine and terrestrial bluff deposits. The amount of sediment delivered to and transported in the nearshore zone are influenced by climatic and environmental factors. For example, the amount of sand derived from rivers and eroding bluffs may also be tied to the time- and climatic-dependent impact of large storms. However, materials eroded from bluffs might be transported offshore and temporarily stored there (see below) . Offshore sources of sand may also be carried onshore into the longshore current sytem at variable rates over time, responding to overall variations in storm intensity and the depth of the wave base (Friedman and Sanders 1978). For these reasons, I interpret the history of the Espenberg spit as a proxy storm history, minimizing the factors of eustatic sea level rise and sediment influx. In a later section, I address climatic forcing on sediment supply. As more data accumulates, researchers will be able to assess any eustatic components.

General Characteristics of the Cape Espenberg Beach Ridge Plain

The Cape Espenberg beach ridge complex is a mainland attached spit issuing from the northern limit of the Seward Peninsula, on the Arctic Circle (66°33' N. lat.) (Fig. 2.2). The spit extends 29 km west to east (at 164° 30' to 165° 15' W. long.) and varies in width from 1 to 2 km. Extensive shoals form east of Cape Espenberg itself (Fig. 2.4), at the entrance to Kotzebue Sound, and an enclosed lagoonal estuary lies to the south.

Four major drainages, rivers or tidal channels, crosscut the Espenberg complex, the Espenberg River being the largest (Fig. 2.5). West of the Espenberg River, the beach ridge complex is bounded to the south by the mainland, while to its east, a spit forms as two islands. The flow of cross-cutting drainages deflected the accreting ridges and, as a result, the pattern, number and spacing of ridges varies between the drainage-subdivided sedimentary packages, termed sub-compexes: A, B, C, D and E (Fig. 2.6). Complexes A and B are west of the Espenberg River, forming a wedge opening northeast from the eroding mainland Kitluk River coast. In its midsection at the C complex the coast undergoes a pronounced realignment, curving toward the south. By the most easterly E complex, the coast is oriented to the southeast. Nearly half of the longitudinal extent of the spit lies in the insular E complex.

At its western attachment to the mainland, the Espenberg spit complex is seaward of a slight scarp (10-15 m MSL) forming the contact with older Pleistocene age deposits (Fig. 2.5). Numerous circular or oval thaw lakes and marshy basins interspersed with polygonal tundra characterize mainland topography. By contrast, the surface of the

Fig. 2.5. Aerial Photograph of a portion of the Cape Espenberg beach ridge plain. The mainland is marked by thaw lakes and is separated from the ridges by a low, but prominent scarp. The Espenberg River, in the center of the photo, and a smaller channel to the east subdivide the ridge plain into complexes. As discussed in the text and shown in Fig. 2.6, the complexes illustrated above are the B, C and D complexes.

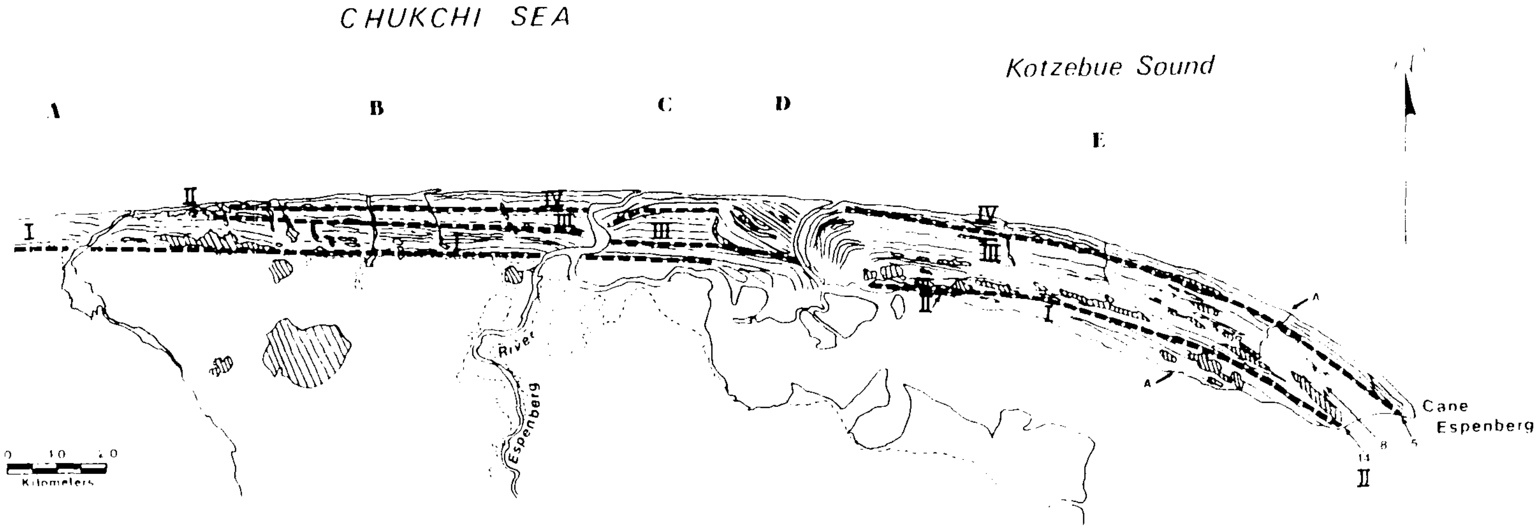

Fig. 2.6. **Depositional Units at Cape Espenberg. Letters (A,B,C...) indicate the complexes formed due to the through-flowing drainage of rivers and inlets. Ridges are numbered sequentially landward. Depositional units are numbered by Roman numerals, following standard geological practice, ie. I is the oldest.**

Espenberg complex is formed by discrete shore parallel ridges, separated by inter-ridge swales of variable width. The ridge and swale sequence records a progradational sequence since the Holocene stabilization of sea level.

In ridge designations I follow the conventions set by J.L. Giddings (1963) who numbered ridges at nearby Cape Krusenstern sequentially increasing landward from the modern beach. Three types of shore-parallel terrestrial ridges occur at Espenberg (Figs. 2.7-2.9):

(1) **Smooth ridges (=berm or planar ridges)** are low in elevation, ca. 1.5 to 2.0 m above sea level, and lack substantial sand dunes but may contain traces of former blowout basins (Fig. 2.7). Dunes on these ridges are sparsely distributed and extremely low. Stratigraphically, smooth ridges show bedding inclined seaward and may correspond to berms found at the highest tide line.[2] Swales between successive smooth ridges are very wide and have been the site of extensive peat and palsa (ice cored hummock) development. Since berm ridges are above most spring tides, some measure of storm-influenced elevation of water level must be involved in their origin.

(2) **Dune ridges** are accretional and bell-shaped, with slopes up to 30° (Fig. 2.8). Formed as sand from the backbeach is trapped by lyme grass (*Elymus arenarius mollis*), dune ridges may attain heights of up to 20 m, but are generally only 5.0 to 6.0 m in height. Swales between dune ridges are comparatively deep, narrow and are commonly filled by ponds.

(3) **Blowout ridges** form as a consequence of the disruption of the vegetation cover on dune ridges (Fig. 2.9). Such disruption may result from storm surge attack, trampling, fire, plant mortality etc. (Mason 1988c, this volume, Ch.3). Blowout ridges often record several periods of erosion and re-deposition; containing numerous buried surfaces or incipient paleosols. Considerable topographic complexity results as eolian erosion produces nested blowouts, coalescing deflation basins and residual dune masses similar to the evolved foredunes of eastern Australia described by Hesp (1988).

The three types of ridges correspond to different depositional environments (cf. Mason this volume, ch. 3). Dune and blowout ridges require the (a) a supply of sand on the backbeach, (b) high winds capable of moving the sand, (c) moisture conditions

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[2]An alternate hypothesis could invoke transient sea level changes of several meters during the time of berm ridge formation. Clark and Lingle's (1979) model for eustatic sea level response does predict that sea levels in the Chukchi Sea were above modern (less than 1 m) from after 3000 until ca. 500 B.P.

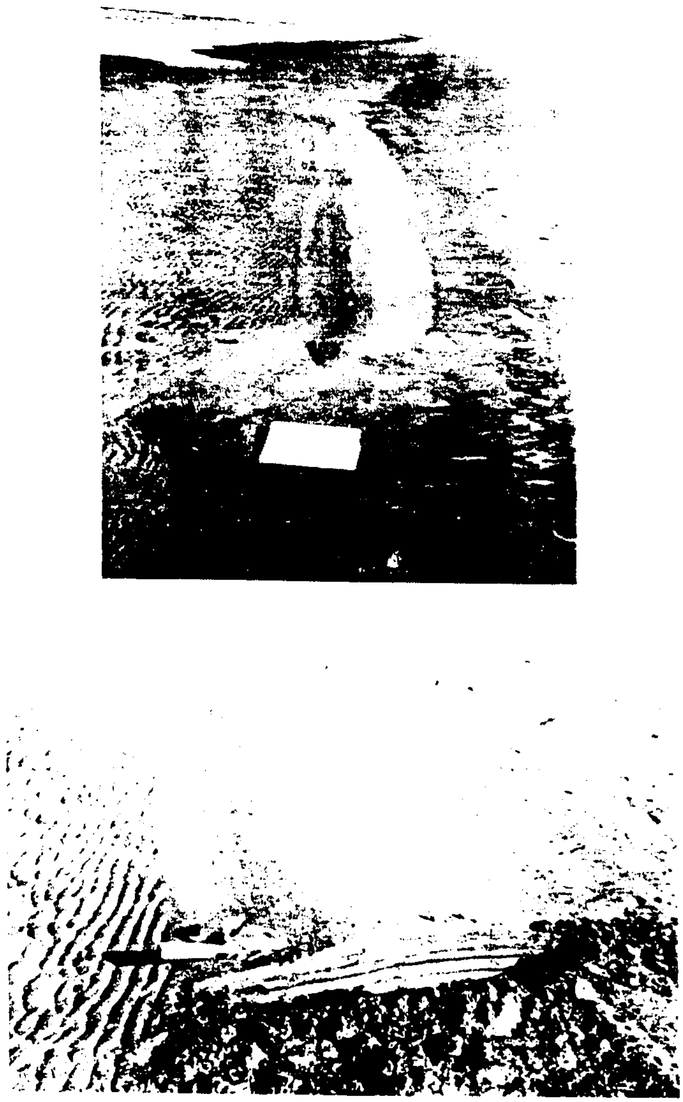


Fig. 2.7. Photograph of a berm ridge, forming in the swash zone during fair weather conditions dominated by low wave energy. Wider, higher berm ridges form in the back beach in the waning phases of storms.

Fig. 2.8. Photograph of a dune ridge, mid-June. This photo shows low unvegetated dunes in the back beach which developed during the late winter. The dune in the background is about 5 m above MSL and is bound by lyme grass. A prominent scarp into the lower portion of the dune reveals an episode of marine erosion, probably the 1974 storm.

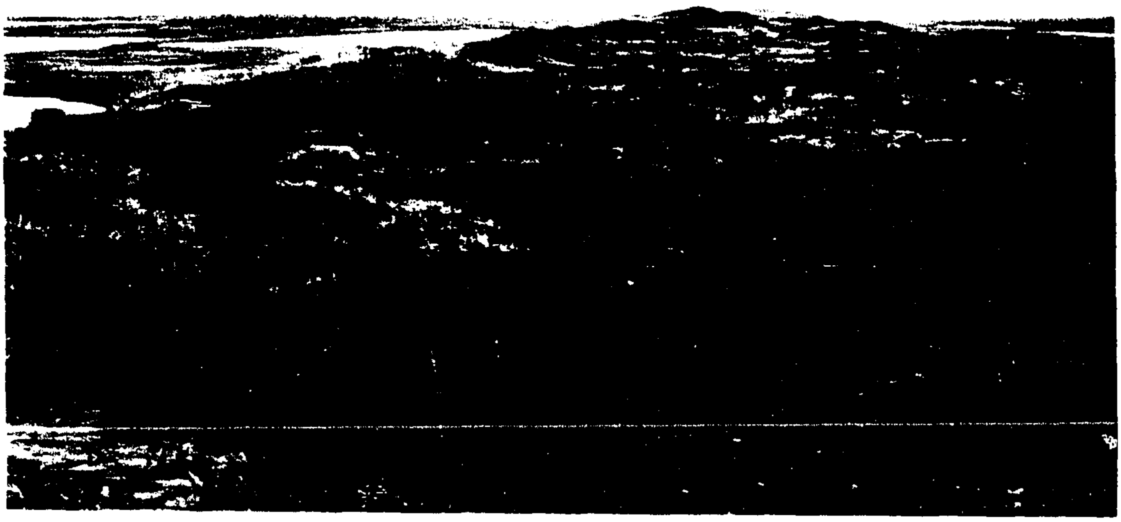


Fig. 2.9. Photograph of a blowout ridge, E-14. The hummocky topography is produced after several cycles of blowout development over the last 3000 yrs. Seasonal ponding occurs in blowout basins, as evident from the presence of rushes (*Juncus* spp.).

that allow it to be moved (Greeley and Iversen 1985); and (d) the occurrence of sand capturing plants (Pye 1983a, Hesp 1984). The first two conditions develop best with stormy conditions prevailing at present in late July to September.

Dune-building is likely a multi-seasonal process (Mason this volume, ch. 3). Storm surges occur with greatest frequency in September to November (Wise et al. 1981), while sand movement and deposition in the back beach may occur in late winter (Fig. 2.7). For example, as sand is delivered onto the back beach by autumn storm washovers, it is then available for wind re-transport during the winter (Ritchie and Penland 1988). Ridges without dunes, by contrast, indicate comparatively less windy conditions, saturation of sediments by rain or groundwater or an absence of grasses, if ridge soils remain too saline (Godfrey 1977, Godfrey et al. 1979). Fair weather (and calmer post-storm) conditions prevailing in July/August generate part of the deposition of berm ridge accretion.

The number of discrete ridges and the vertical thickness of sand varies longitudinally, west to east, across the 29 km of the Espenberg spit (Fig. 2.6). Only five ridges occur in the westernmost A complex, while twelve laterally continuous ridges are apparent in the middle C complex. Up to 20 principal ridges and up to 20 additional sub-ridges form in the easternmost E complex. Conversely, the highest portion of the Espenberg spit lies in the west, with heights of up to 20 m in the B complex, decreasing to 14 m in the C complex and 10 m in the E complex, based on elevations on USGS geodetic survey markers on topographic maps.

The Espenberg spit shifts radically in direction 5 km east of the Espenberg River and the C complex; eventually it is oriented to 120.° The shift in coastal orientation at the C complex curvature reflects changes in longshore transport and storm surge effects. Evidence for this action may be the storm-related ice push and wallow features (cf. Hume and Schalk 1964) observed in June 1989 on the back beach of the C complex but not on the downdrift E complex (Fig. 2.10). East of the C complex, transport energy markedly decelerates and results in increasing deposition. This circumstance mirrors the pattern for the spit as a whole, as explained by Sharma (1984:404) who uses satellite imagery to interpret sediment concentration and to infer diminished current strength at the entrance to Kotzebue Sound.

The E complex was formerly an island due to the presence of a 1 km wide channel between complexes C and E. This infilled channel, delineated by recurved ridges (Figs.

Fig. 2.10. Photograph of ice push features on back beach of the C complex at Cape Espenberg. During the previous autumn a storm pushed blocks of ice onto the beach. After melting the resulting basins and settling lags were produced. Note fluvial channels and ripples.

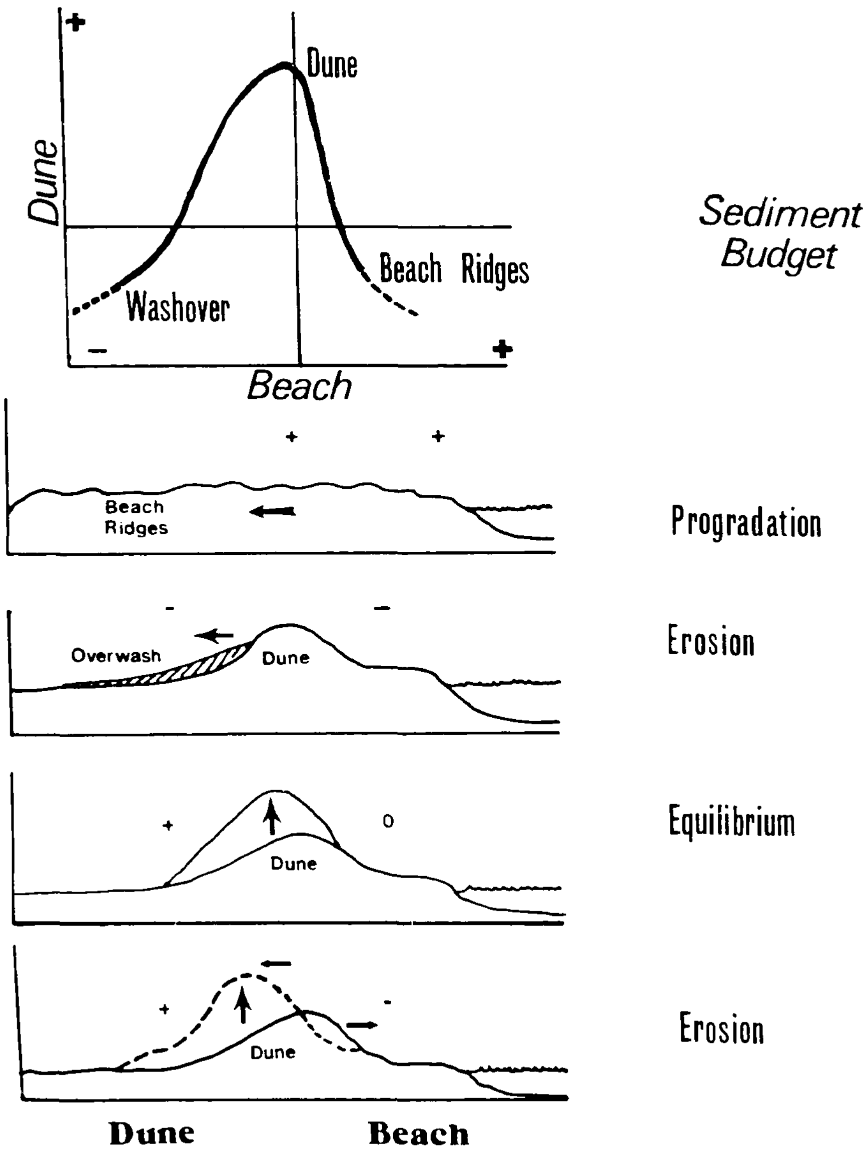
2.5 and 2.6) acted as a temporary sediment sink which must be filled or bypassed. The entire D complex, deposited within the C/E inlet, is part of this sediment sink produced partly by updrift erosion of the Kitluk bluffs or of older portions of the Espenberg complex. In effect, the spit may grow partially by cannabilizing itself.

Individual ridges bifurcate towards the terminus of the spit, following the model of berm ridge development proposed by Hine (1979) for spits in Massachusetts. The amount of sediment deposited varies with storm and tidal range (neap vs. spring) coupled with the ability of waves to overtop preceding deposits. Several types of berm ridges are recognized by Hine: (a) neap berms--built during low energy periods; (b) intertidal swash bars producing a characteristic ridge and runnel topography; and (c) berm ridges building atop swash bars at spring high water. This last pattern gives rise to ridges separated by wide swales reflecting an increase in beach growth towards the tip of the spit due to the decreasing longshore transport of sediment and shifts in shoreline orientation.

The heights of individual ridges vary in the landward direction. A series of six dune ridges (E-1 to E-5), up to 6 m high, is within 0.5 km of the sea. Isolated dune ridges are found between 0.68-0.74 km (E-8 ridge), 1.49-1.53 km (E-12 ridge) and 1.7-1.9 km (E-14 ridge) from the sea. Otherwise, the Espenberg ridges are low in elevation; 1.5 to 2.0 m above MSL, an elevation three times the 50 yr storm surge height calculated for Shishmaref by Peratrovich and Nottingham (1982, see above). The alternation between dune and low beach ridge facies at Espenberg fits into a paradigm of storm and fairweather controlled deposition.

Mechanisms of Dune Growth

To understand the development of dune and beach ridges at Espenberg, it is necessary to consider the interaction between the beach and the dunes. Ultimately, these locations are different means of sand storage which reflect the energy level affecting the shoreline and the balance between progradation and erosion (Fig. 2.11) (Psuty 1988, Ritchie and Penland 1988). A proxy measure of the erosion rate is useful; beach width provides this referent (Clark and Elliot 1983). Using aerial photographs, I measured beach width as the distance from the swash zone to a prominent scarp on the first dune ridge.



(after Psuty 1988)

Fig. 2.11. Relationship between erosion and deposition as reflected in sediment storage in dunes or on the beach. Dune -building is associated with an erosive regime with large pulses of sediment onto the beach while horizontal accretion occurs with fewer, less massive storms.

Variation in beach width reflects the distance between the low energy swash zone and the incipient dunes. Infrequent high intensity storms reach and undercut the incipient dunes. The mid- and backbeach zones contain a variety of drift debris: logs, tree-limbs, Pleistocene bone and shell, modern shell, starfish, seal, walrus and other animal carcasses, as well as modern industrial trash. This debris is sorted by size at various distances landward between the swash zone and the dunes. The backbeach widens as a result of heightened deposition at shifts in coastal orientation and the re-depositional overwash of the occasional storm surge (Cleary and Hosier 1979, Davis 1985, Leatherman and Zaremba 1987). Beach width is related to the degree and frequency of net beach erosion or deposition along a particular stretch of coast. The process of longshore transport of sand resembles a periodic step function. Sand is transported downdrift episodically, building incipient dunes and is placed in storage. On occasion, such dunes are subjected to wave erosion which re-transports sand several hundred meters further downdrift followed by another period of temporary storage. The construction of most dune ridges may be based on such upcoast erosion, down coast re-deposition since the entirety of the coast would not be effected by a single storm.

The stepwise nature of the erosion/redeposition process shows up in beach width variations. The width of the modern beach at Espenberg varies considerably longitudinally from a minimum of 10 m in the western B complex up to 120 m in the eastern E complex (Figs. 2.12 a,b,c) (Mason, 1988, unpublished data). Beach width in the A and B complexes (Fig. 2.12a) oscillates in a wave-like manner within a wide range--between 20 and 80 m--revealing the episodic nature of erosion and in this rthythmic pattern mirrors the process of longshore transport. In the C complex, in the middle of the Espenberg complex, beach width is fairly constant--between 40 and 60 m (Fig. 2.12b). Beach width increases greatly at inlet margins--nearly 160 m at the B/C inlet and over 300 m at the D/E inlet. Such inactive inlets serve as sites of temporary storage for a considerable amount of sand. The 10 km long E complex shows considerable variation in width, from as high as 200-370 m near the D/E inlet in the west to low as 28 m at the east, though width in the E complex is generally 60-80 m (Fig. 2.12c). Variability in beach width is paralleled by a record of variable foredune erosion. Erosion during the period 1949-1976 was greatest in the B complex, 0.5 m per yr, and lower in the E complex, about 0.38 m per yr (J.W. Jordan 1988: 348ff).

The relationship between beach width and the amount of dune building is important in explaining the tempo of deposition at Espenberg (Figs. 2.5, 2.6). In areas

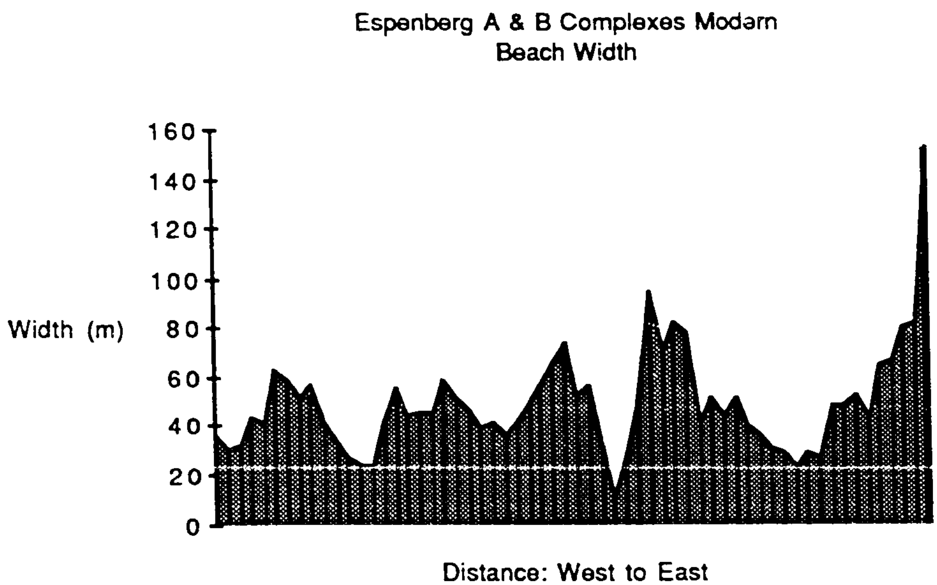


Fig. 2.12 a. Beach width in the A and B complexes at Cape Espenberg. Beach width, measured from the swash zone to the eroded scarp on the first dune ridge, provides an indication of balance between erosion and progradation at Espenberg.

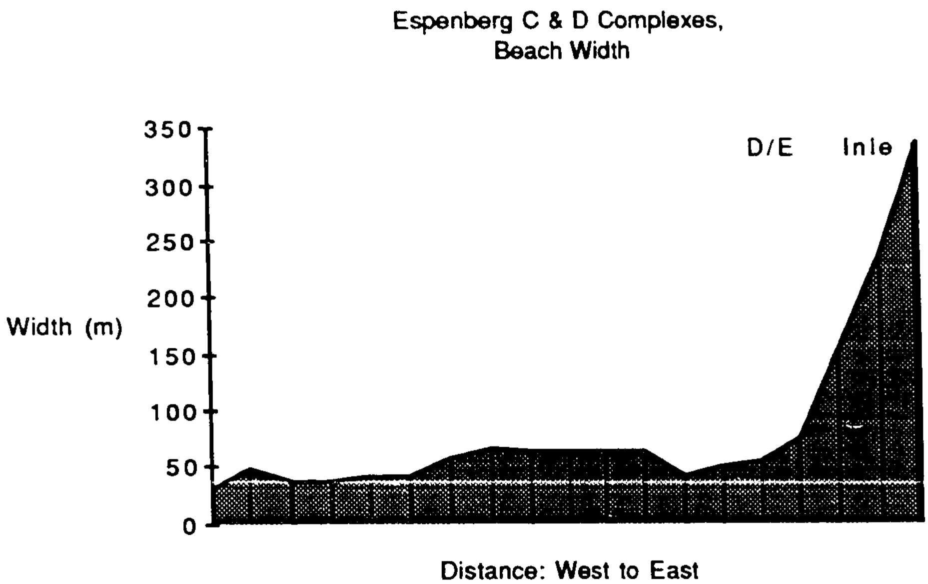


Fig. 2.12 b. Beach width in the C and D complexes at Cape Espenberg. Note the increase in width at the D/E inlet margin.

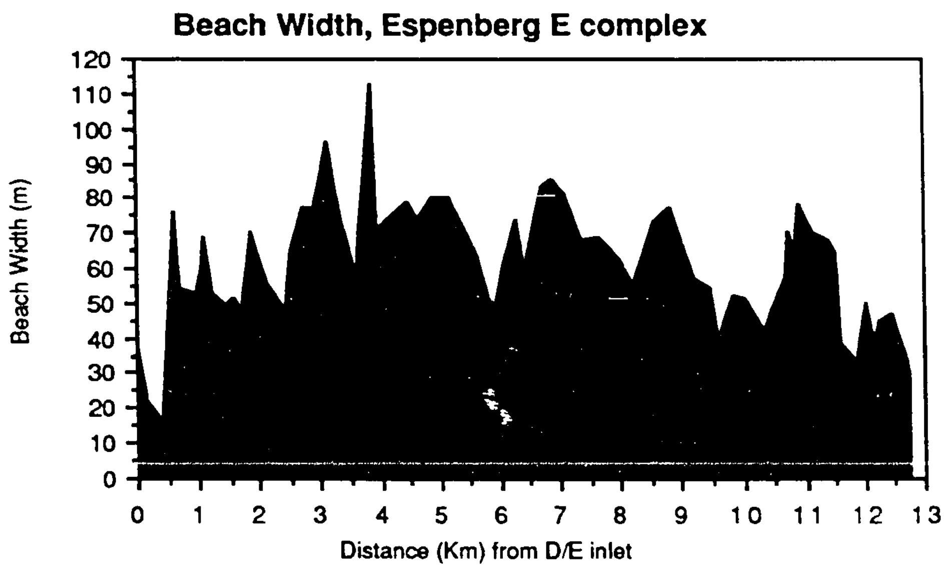


Fig. 2.12c. Beach width in the E complex at Cape Espenberg.

with widest beaches, as in the easterly E complex, the dunes are lowest. Accretion is horizontal in direction with the vertical addition of numerous small dunes, rather than a single high ridge (Fig. 2.11). By contrast, a single high dune is building in areas with narrower beaches in the western B and C complexes. Such beaches are erosional in character. As defined theoretically by Psuty (1988), sand is stored in the beach in aggradational areas while it is stored in dunes in eroding areas. The patterns of growth at Espenberg is explainable as a contrast between *vertical* dune building under erosional conditions and *horizontal* progradation with little dune growth with sand surplus, as seen below from a historical perspective (cf. Fig. 2.16, Mason this volume, ch. 3).

Seasonal differences in beach topography and sediment composition are striking. During low energy, open water conditions, distinctive triangular cross-section swash bars several tens of meters long are added atop the planar erosional surfaces produced by storm events (Fig. 2.7). With limited wave influence during the summer, the backbeach is subject to eolian erosion which produces shallow deflation hollows, pedestalled shells and debris. During winter, the back beach is also subject to eolian processes, producing low dunes of amorphous shape (Fig. 2.8). In addition, ice may be occasionally rafted onto the backbeach by autumnal high water, resulting in 0.5 m deep craters, interstratified marine sand deposits and melt-out features (Fig. 2.10). Most of these sedimentary features have low preservation potential.

To examine beach stratigraphy, several series of trenches were excavated across the modern beach. A midbeach profile (Fig. 2.13) shows some typical features: there are planar, subhorizontal deposits (0° to 3° landward) and deposits that are obliquely inclined seaward (up to 10°). Seaward inclined units are often traceable for several meters and include thick, sequences of discrete 1 mm laminae with coarser tephra sands and shells. This alternation in depositional units reflects the angular disconformity produced during storm erosion, followed by deposition during waning phases of the storm. The succeeding horizontal bedding reflects the recovery after the storm. During calm weather periods ridge-runnel features and swash bars of variable width and height are added atop post-storm horizontal beds. Ridges or swash bars may show steeply inclined beds (20°-35°) inclined in both landward and seaward directions. Grain size parameters show that the dark mineral beds are considerably coarser (1.5 ø) than the light mineral beds (2.0-2.2ø).

The net product of beach processes is a beach ridge, defined by Reineck and

Fig. 2.13. Photograph of beach stratigraphy at Cape Espenberg. The dark wedge of tephraeous sand was deposited during a single storm episode.

Singh (1980:352-3): "a continuous linear mound of rather coarser sediment near the high water line... develop[ing] mainly during storms and exceptionally high waters." At Espenberg, only rarely is it possible to observe primary beach ridge structure from surface exposures or by excavation due to the shallowness of water table. Consequently, only the dune facies is usually observeable from surficial excavations or cutbanks.

Methods of Correlating and Dating Beach Ridges

The stratigraphic description of beach ridge deposits requires a special approach by the Quaternary geologist. Such deposits may be termed a depositional facies of a lithostratigraphic unit (North American Stratigraphic Code, 1983), being stratified sediments, derived from common lithic materials, resulting from common genetic processes, with easily definable contacts and these lithostratigraphic units are related to a particular time period.

Describing and correlating beach and dune ridge deposits requires diverse methods. In this study chronologic referents are provided by radiocarbon dates primarily obtained from archaeological investigations. I delineated depositional facies using aerial photos, subject to several criteria; relying primarily on vegetational and topographic differences between sand ridges, as supplemented by stratigraphic, pedologic and granulometric characteristics.

Patterns on Aerial Photographs

I used aerial photographs to delineate depositional boundaries by referring to geomorphic features such as drainage, scarp development, slope breaks and vegetational differences. As is well known, color differences in the infrared portion of the spectrum clearly record differences in moisture content, plant cover and/or lithology. Three sets of photos were used: (1) the standard false color infrared U-2 imagery shot at 1:60,000 scale, (2) the National Ocean Survey (NOS) natural color infrared imagery at 1:30,000 scale and a (3) a false color set shot at 1:8,000 scale from fixed-wing aircraft, commissioned by the National Park Service (Anchorage Regional

Office). The two smaller scale photo sets are archived by the Geo-Data Center of the Geophysical Institute, University of Alaska.

Photo-interpretation and Field Observations

My study of the Cape Espenberg beach ridge plain involved both field work and air photo interpetation. I relied solely on aerial photos for about half of the ridge complexes: most of the A, B and D complexes and the western quarter of the E complex. Otherwise, I traversed portions of the A and B complex and most of the C and E complexes. Due to cooperative logistic and archaeological concerns, my initial base camp in 1986 lie in the easternmost E complex near the Espen USGS survey marker. Hence, many of my field observations were made in this area. As it has turned out, the region is a suitable type section for the entire complex since longshore current strength diminishes in this area and a depositional regime predominates.

Radiocarbon Dating

A suite of 37 radiocarbon assays exists (Table II-g, Figs. 2.14a,b; 2.15) for the Cape Espenberg region. The radiocarbon samples were collected from archaeological components (87%) in exhumed or eroded paleosols within blowouts, at cutbanks, or from subsurface test excavations (Schaaf 1988a, 1988b, Harritt 1989, 1990). For the most part, the collection biases of archaeologists favored charcoal over wood when a variety of materials were available (97%). A single date was obtained on a sample of a tar-like, indurated charred sands, bound by sea mammal fats. Two samples consisted of a mixture of uncarbonized organics and wood. Geological samples (13%) derived from exposed subsurface grass horizons (n=3, or 8%) or marine shells (n=2 or 5%) lying on the surface of landward ridges.

In Table II ^{14}C assays are reported uncalibrated for comparison with the established body of dates and calibrated, using the procedures developed by Stuiver and Pearson (1986) and Stuiver and Reim (1986). Marine dates are also adjusted by a factor of 400 years (Mason and Ludwig, in press; this volume, Appendix) to account for regional reservoir effects associated with oceanic old carbon (Stuiver et al. 1986). The date list is plotted with two sigma values in Figs. 2.14a and 2.14b and in relation to ridge height in Fig. 2.15.

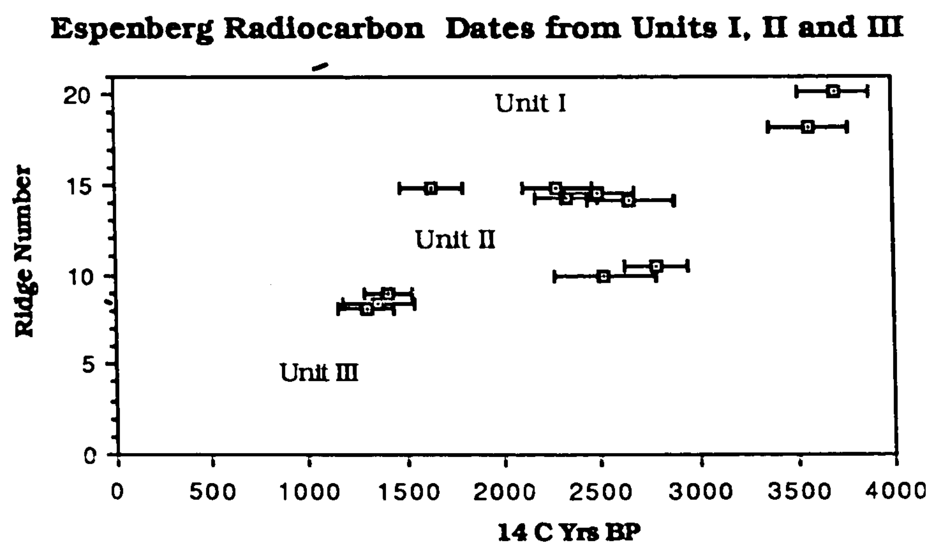


Fig. 2.14(a). Plot of radiocarbon ages (cf. Table II-g) from Cape Espenberg, Units I to III. Two sigma ranges are given as an error bar. Ridge location is plotted on the Y axis.

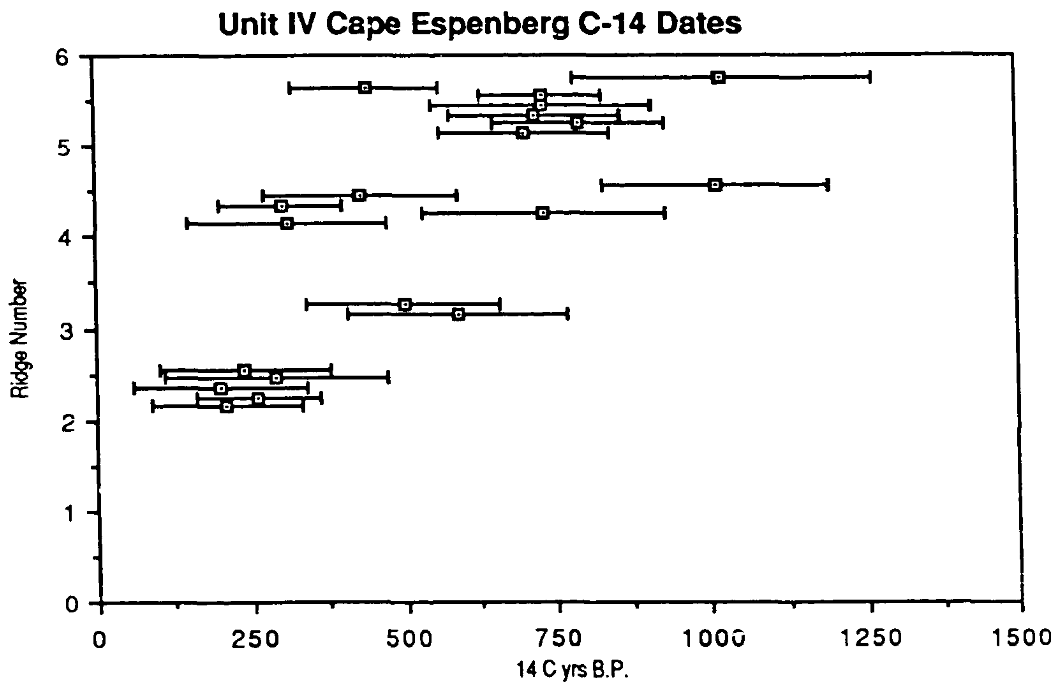


Fig. 2.14 (b). Plot of radiocarbon ages (cf. Table II-g) from Cape Espenberg, Unit IV. Two sigma ranges are given as an error bar. Ridge location is plotted on the Y axis.

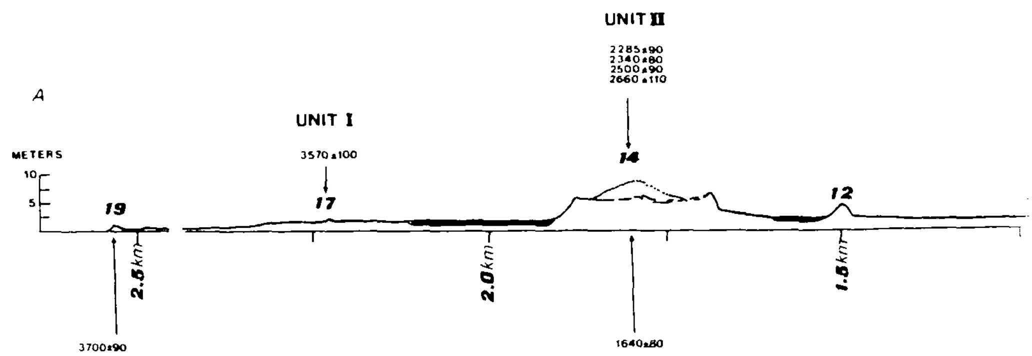
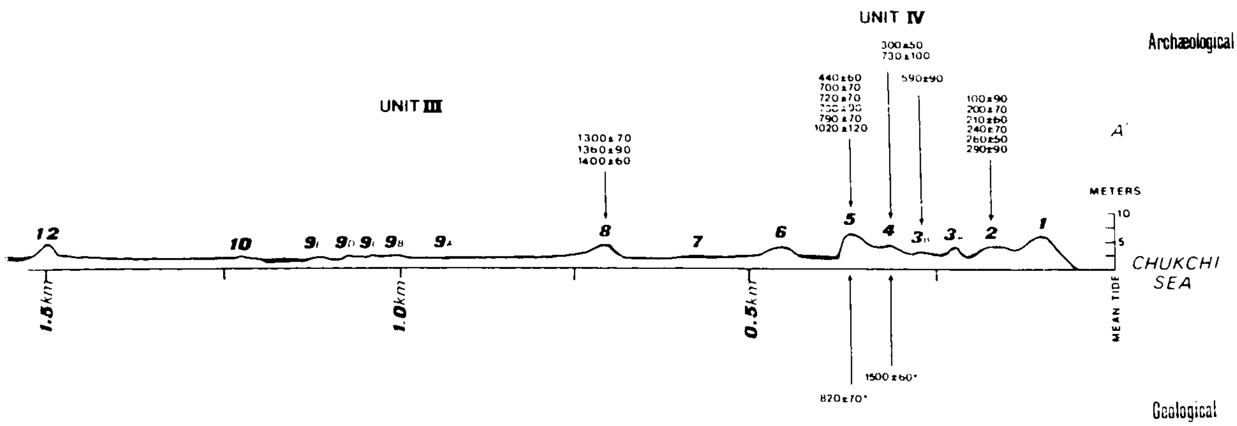


Fig. 2.15. Radiocarbon dates from Cape Espenberg plotted in relation to ridge elevation. Note the vertical alternation in ridges moving landward. Dune ridges are clustered in two discrete intervals: 3300-2000 BP and after 1200 BP.


UNIT IV
Archæological
300±50
730±100
440±60
700±70
720±70
790±70
1020±120
590±90
100±90
200±70
210±60
240±70
260±50
290±90
A'
UNIT III
1300±70
1360±90
1400±60
METERS
10
5
12
10
8
7
6
5
4
3
2
1
CHUKCHI SEA
MEAN TIDE
1.5km
1.0km
0.5km
1500±60*
820±70*
Geological

Tephra

A well-dated ash was found on the oldest beach ridge and allows the correlation of dune ridge formation with the widespread ashfall event.

Archaeological Remains

The regional cultural chronology plays a substantial role in the dating and correlation of sedimentary deposits in northwest Alaska. Summarized in Table III, the cultural sequence extends over 4000 years and likely represents the occupation of coastal Alaska by the ancestors of Eskimo (Yup'ik and/or Inupiat) people (Giddings and Anderson 1986, Dumond 1987). Diagnostic artifacts and house types provide critical time referents and have been used in a manner similar to index fossils. The earliest, pan-regional archaeological horizon dates to 4000-3500 BP. This horizon, termed the Arctic Small Tool tradition (ASTt), is marked by distinctively pressure-flaked microlithic technology, fire hearths, circular dwellings and the absence of ceramics. After the initial occupation of ASTt peoples, more localized archaeological cultures, termed Choris, Norton, Ipiutak, western Thule etc. are distinguished sequentially, primarily on the basis of decorative motifs on harpoon heads and ceramics, changes in the shape of houses from round/oval to rectangular and subterranean, with lithic artifacts increasingly made on ground slate.

Granulometric Analysis

Variations in grain size parameters such as the mean, skewness and kurtosis are widely considered to provide inferences about the current strength and depositional environments, the provenance of sediments and so on (Mason and Folk 1958, Shepard and Young 1961, Visher 1969). To these ends, I collected samples from several areas of the Cape Espenberg ridges.

A total of 105 samples were collected for grain size analyses from the Cape Espenberg spit during 1986-1988. Samples are from all three types of ridges, though the dune context may be over-represented. This circumstance is due to limitations on depth of excavation possible due to the presence of permafrost, the water table and the exclusive use of a shovel. Generally, samples of about 250 g were collected from depths of about 20-30 cm on beach or dune ridge surfaces.

Three sample strategies were employed. First, single samples were obtained longitudinally (every 250 m) and latitudinally across the complex (each ridge): ie. parallel to the coast and in two traverses across all four depositional units. Second, several ridges were selected for more intensive sampling: ie. a series of six sample stations were selected as representative of differing slope orientations on a ridge. Finally, deeper samples were extracted from cutbank or archaeological exposures.

Laboratory procedures followed Lewis (1983) using nested sieves at 0.25 Ø intervals, subjected to mechanical shaking for 15 min. Statistic parameters were calculated following Folk and Ward (1957).

Soil Development

Soil profile development in sandy sediments varies considerably with the stability of the surface. Thick surficial organic (O and /or A) horizons, ie., epipedons (Soil Survey 1975), are common in stable, non-deflated areas covered by crowberry (*Empetrum nigrum*) and other low shrubs with horizontal root systems. In unstable areas subject to seasonal ponding and desiccation oxidation of iron grains results in mottling and pronounced alteration of the sediments, ie. coating of individual grains. Episodic ground water percolation displaces heavier grains downward to produce distinctive tongue-like features. This process of iron eluviation forms spodosols and secondary compounds such as goethite (Pye 1983b).

In areas subjected to active eolian processes, including young dunes, soils are less developed and consist only of thin silt laminae. These silt accumulations occur as silt is eluviated from surface horizons, moves downprofile and is deposited upon reaching a moisture and pore space gradient (Soil Survey 1975).

Cryogenic alteration is particularly common within the Espenberg ridges. Distinctive features such as wedges, loading structures and convoluted beds occur primarily on better drained ridges where a pronounced difference exists between an impermeable lower, frozen layer and the upper seasonally thawed/re-frozen zone at about 1-2 m depth (Vandenberghe 1989). Troughs and wedges are common on ridges that are 750 years or older. Such structures provide useful information for climatic reconstructions; for instance, ice wedges indicate a low snowcover in autumn which results in cracking and later infilling by blowing snow or sand during the winter.

Vegetational Differences

The topography of the Cape Espenberg spit is governed in large measure by plant community dynamics (Mason this volume, ch. 3). Dune ridges build vertically due to the high tolerance of beach grass (*Elymus* spp.) for burial by sand (30 cm per annum) and its ability to root deeply (several meters) and expand laterally by rhizomes (Chapman 1978, Ranwell 1972). The vertical component imparted by beach grass is matched by the horizontal nature of the root systems of prostrate shrubs such as crowberry (*Empetrum nigrum*) and willow (*Salix* spp). The latter two species, intolerant of sand burial, provide a stabilizing influence and are favored as the beach migrates seaward, isolating growth sites from the active sand source on the beach. In water-saturated inter-ridge (swale) areas, specialized biotic assemblages of sedges, sphagnums and tussocks predominate. The contrasts between the different plant communities are readily observeable on infrared aerial photos and provided a means to delineate depositional units.

Lakes and Palsas

Lakes and ponds form readily within inter-ridge swales on the Espenberg spit. Lakes range in size from less than 0.1 hectare to more than several km^2 in area (Racine 1977). The source of the water seems to be largely, if not entirely, precipitation, with seasonally high evaporation leading to fluctuations in lake level. Former strandlines are easily recognized within swale ponds and complete desiccation of some ponds has occurred in some blowout basins. Variation in altitude above groundwater table and distance from the sea contribute to differences in lake-margin and bottom vegetation.

The development of swale lakes is complicated by the presence of permafrost and the biochemistry of peat. The presence of peat furthers the growth of permafrost by maintaining cold temperatures in the ground surface. Peat degradation contributes to the expansion of lakes because as nutrients are exhausted, only comparatively sterile water remains (D.M. Hopkins, 1986, field notes). Ice-cored hummocks, palsas, form within swales under sparsely snowcovered peat as segregation ice is subject to up-doming cryostatic pressure (Sepällä 1988).

Blowout Evolution

With increasing age, the coastal dunes at Espenberg undergo several changes in morphology. Blowouts develop as the economy of the dunes shifts from one of sand surplus to one of sand deficit and as the dominant plant cover shifts from grasses to prostrate shrubs. Diverse sizes and a complex inter-connected topography of blowouts results (Fig. 3.3), Mason this volume, ch. 3.). Older ridges show multiple generations of blowouts, revealed by exposed paleosols and nested blowout basins.

Summary of Techniques for Correlation of Beach Ridges

Depositional units are defined at Espenberg on the basis of vegetational differences, changes in granulometric parameters, post-depostional pedogenic and cryogenic modifi-cations and lake or palsa formation. For age estimates I primarily use radiocarbon dates from archaeological and geological contexts, supplemented by references to tephra marker beds. The following presents my reconstruction of the late Holocene geomorphic history of Cape Espenberg.

Depositional Units of the Espenberg Beach Ridge Plain

I delineate four units to form a horizontal stratigraphy at Cape Espenberg (Figs. 2.6, 2.14, 2.15, 2.16). For ridge designations I follow the conventions set by J.L. Giddings (1963) who numbered ridges at Cape Krusenstern increasing in sequence landward from the modern beach; hence, E-1, E-2, etc. A discontinuous ridge fragment is denoted by a suffix: ie., E-2-c.Depositional unit designations follow geological practice (Fig. 2.6, 2.16),using Roman numerals in an oldest to youngest ascending numeration. **Unit I** formed before 3800 BP; **Unit II** prior to 3300-2000 BP; **Unit III** between 2000-1200 BP and **Unit IV** after 1200 BP to the present. The four units at Cape Espenberg reflect alternations between conditions of high wind and storm

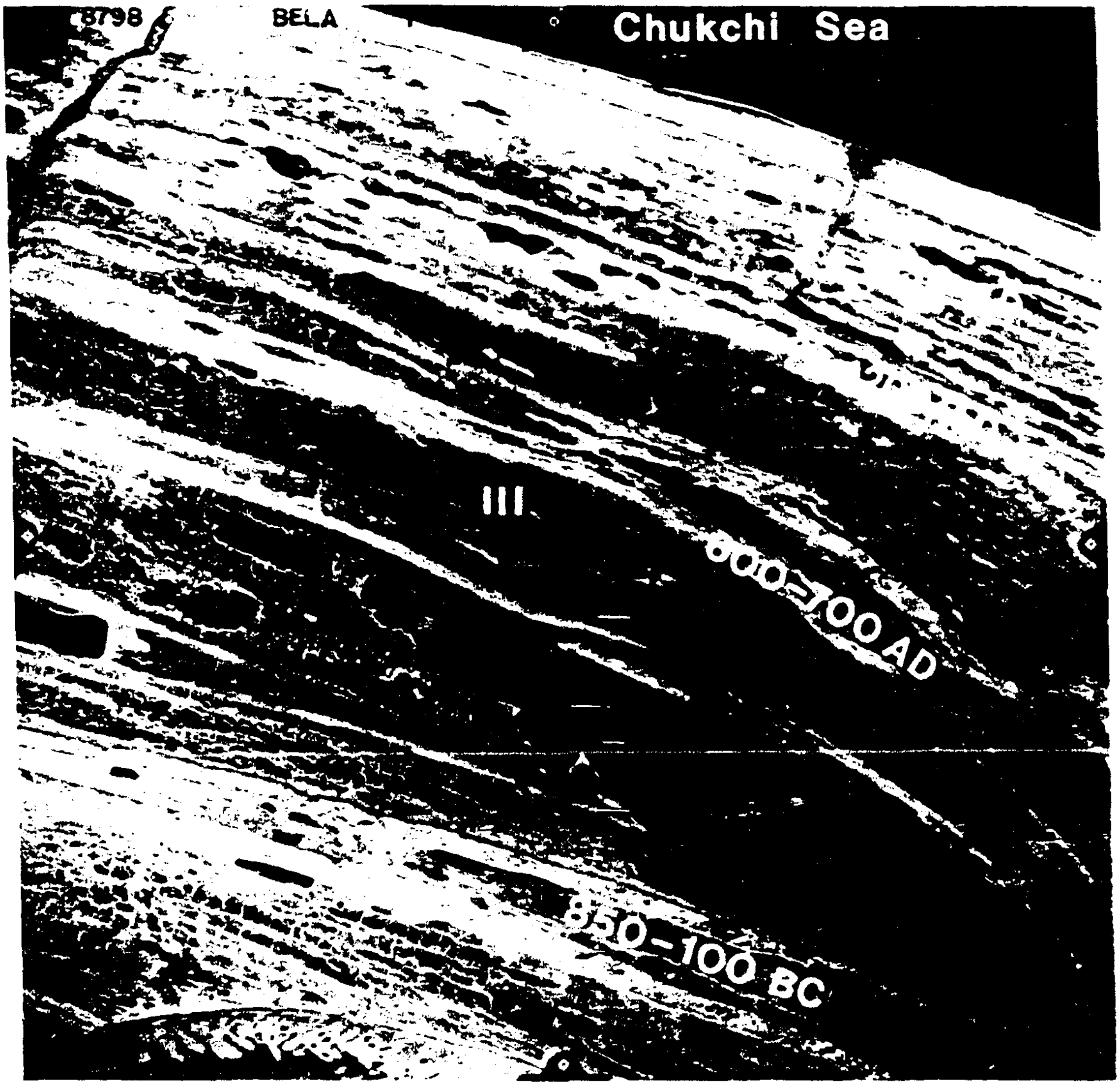


Fig. 2.16. Aerial Photograph showing a portion of the Cape Espenberg E complex, with depositional units and calibrated ages on some of the ridges. Blowouts are apparent by the greater reflectance of bare sand.

intensity and those of less storm intensity.[3] Radiocarbon constraints on the ages of the units are plotted in Figs. 2.14ab and 2.15.

On aerial photos, the units are distinguishable by differences in moisture content and vegetation (Figs. 2.5, 2.16). The most seaward units show a greater albedo, reflecting more light due to a less complete vegetation cover, predominately of grasses on actively accreting dune ridges and modified blowout ridges. Conversely, a darker, less reflective region in the midsection of Espenberg contains a series of marsh covered, low-lying berm ridges with wide swales. The signature of blowout ridges shows much exposed unvegetated sand with concentric basins.

Granulometric Delineation of Depositional Units

Distinguishing Beach from Dune Facies

Descriptive statistics on the 105 sand samples collected from the Cape Espenberg spit are presented in Figs. 2.17-2.19, which portray the values of mean (Fig. 2.17), skewness (Fig. 2.18), and kurtosis (Fig. 2.19) in relation to horizontal distance across the C and E complexes.

Medium (1.0-2.0ø) or fine sand (2.0-3.0ø) are the primary sediments at Espenberg, with a mean of 2.33ø ± 0.19, within a range of 1.46 to 2.59 ø. However, only four samples are medium sand--less than 2.0 ø(ie., between 0.250-0.5 mm in diameter), two of these were collected from the modern beach and the other two were classified as beach facies based on basal stratigraphic contexts. Samples stratigraphically distinguished as storm derived deposits (ie. distinct dark mineral, tephraeous bands) were coarser in mean grain size (ie. 1.46 or 1.64ø). Dark minerals also contribute significantly to coarser populations found in incipient dune samples, as evident in a plot of the sorting (Fig. 2. 19).

The mean of the beach samples (n=11) is 2.07 ø, exhibiting a range of between 1.46 and 2.37ø and, collectively, a standard deviation of 0.28ø (Fig. 2.20). Values for

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3 As an alternative explanation, eustatic sea level fluctuations may be involved in shifts in the availability of sediment. Along the North Sea coasts, several researchers (Tooley 1985, Lamb 1988, Christiansen and Bowman 1986) argue that intensified glaciation during the Little Ice Age led to a lowering of sea level, up to1 m in extent. The exposure of the nearshore zone and its submarine sand ridges would have provided a plentiful source for eolian transport. At this time, I cannot evaluate this hypothesis in relation to the Chukchi Sea.

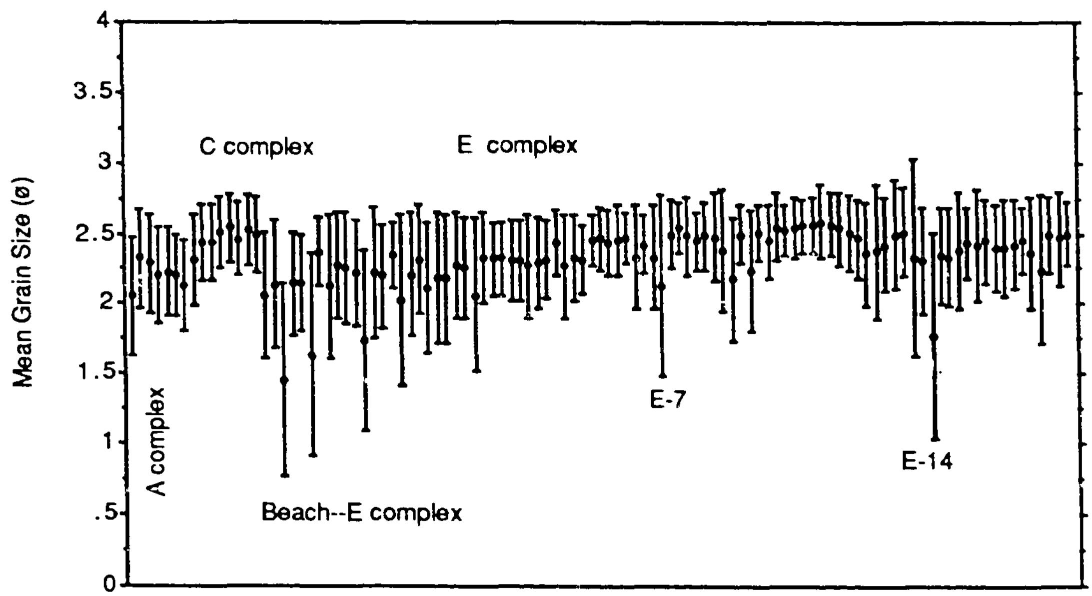

Fig. 2.17. Graphic mean of sand samples from Cape Espenberg beach and dune settings. The sorting is present as an error bar with the one sigma value.

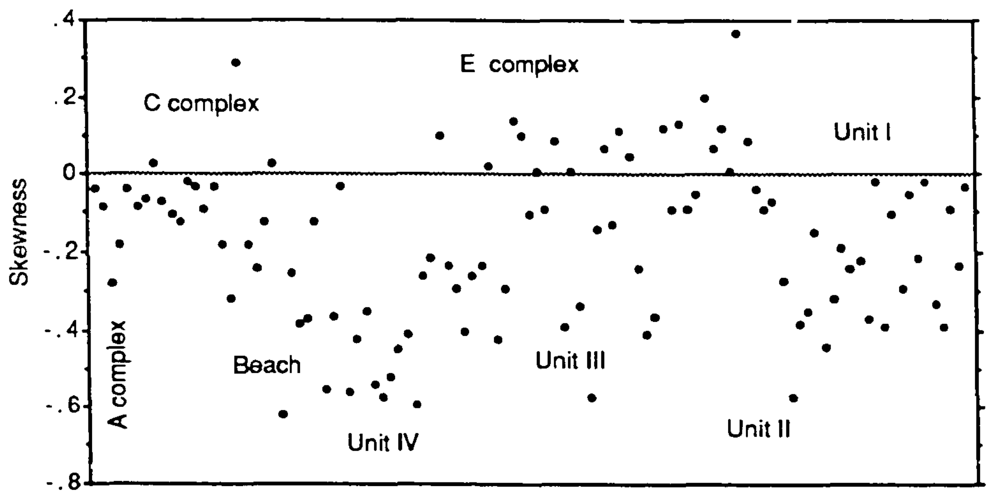

Fig. 2.18. Skewness of sand samples from Cape Espenberg. Note that some of the ridges are more coarse than others, this reflects provenance and storm intensity.

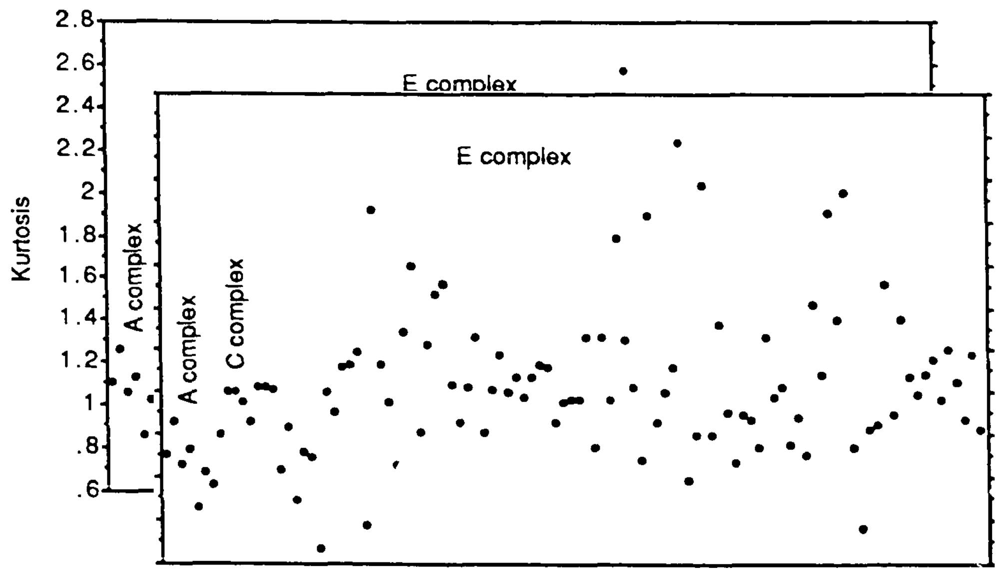

Fig. 2.19. Kurtosis of sand samples at Cape Espenberg. Dune samples are more symmetrical than beach samples, yet no clear trend is demonstrable.

individual samples show either well or moderately well-sorting, but several samples were very well-sorted (ie. <0.35). In terms of skewness, beach samples ranged widely from very negative (coarse) to nearly symmetrical and even positive (fine). The statistics of skewness and kurtosis show no such clear, single hydro- or aero-dynamic pattern; reflecting instead the diverse effects of multiple depositional environments.

For samples collected from dune environments is also similarly contradictory. Generally, the mean grain size on dune ridges ranges between 2.2 and 2.5ø. Individual dunes may show similarities in mean grain size, but often reveal a wide range of particle sizes. For example, on ridge E-14, the Unit II ridge (Fig. 2.21), the mean (n=18) is 2.40 ø with a range of 1.78 to 2.59 ø. Only one E-14 sample, presumably a beach sample, is coarser than 2.0 ø and the majority show a bimodal distribution either between 2.3-2.4 or 2.5ø, reflecting the progressive effects of successive episodes of eolian fractionation. Overall, E-14 samples exhibit a tendency to fine upward; coarser samples are found in the lower dune facies exposed at the cutbank near the cape.

The sorting, the 1 sigma value, does provide an approximation of sample provenience: ie. from the beach or dunes (Fig. 2.17). Beach samples are less well sorted than dune samples; eolian processes are selectively fractionating the samples. Plotting of skewness in relation to sorting may be useful in differentiating between marine or eolian depositional processes (Mason and Folk 1958). However, at Espenberg no clear inference may be drawn using this representation because the modern beach samples fall within several various quadrants of the graph (Fig. 2.22). The hetereogenity of beach samples suggests that several physical agencies or sediment sources are involved. The similarities between dune and beach samples may mean that beaches are composed of marine-eroded dunes and that Espenberg ridges form in a reciprocal fashion, downdrift, as updrift dunes are eroded. This interpretation is substantiated by evidence of recent erosion based on air photo interpretation and variations in beach width both discussed above.

Provenance of Espenberg Sands in Relation to Grain Size

The mean grain size of all Espenberg sediment samples is 2.33ø ±0.19, ie., fine sand. This value differs somewhat from the prevailing size fraction only 1-1.5 km offshore from Cape Espenberg, beyond the nearshore sand bars. Creager and McManus (1966) report that the mean size offshore is about 4 to 5ø, in the coarse silt range. Fine

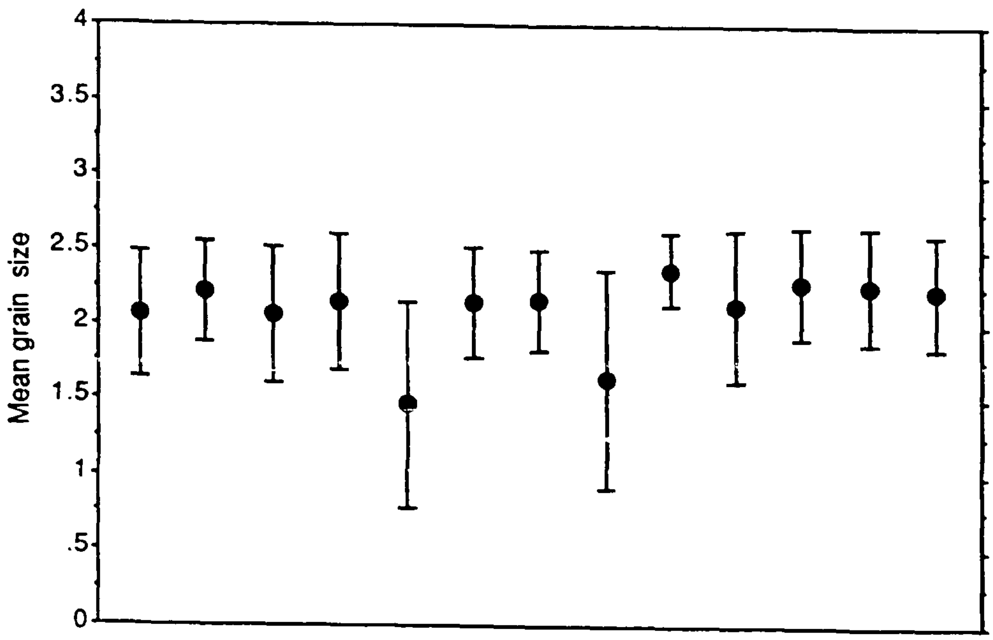

Fig. 2.20. Mean of beach samples from Cape Espenberg..

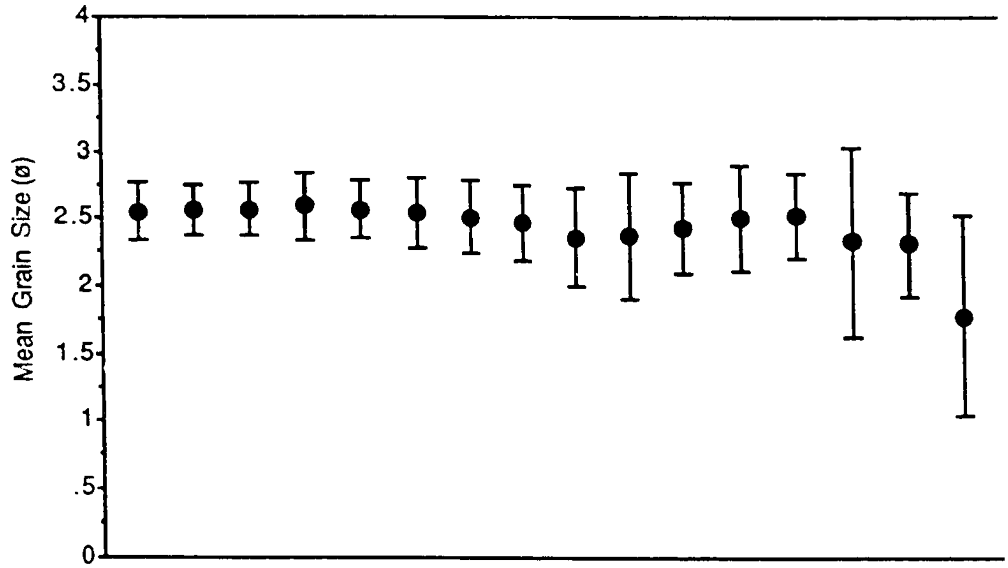

Fig. 2.21. Mean of sand samples from 3300-2000 yr old E-14 dune ridge. Samples on the right are from upper dune facies, while those on the left are from cutbank exposure from lower dune facies and beach facies. Note the fining upward trend.

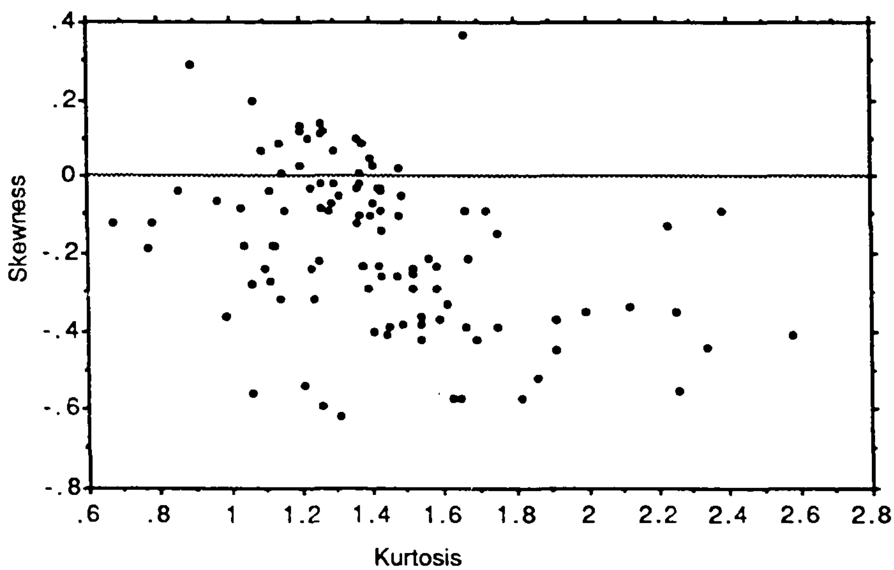

Fig. 2.22 a.

Fig. 2.22. Plot of Skewness in relation to Kurtosis in order to isolate beach from dune facies (a) All samples (b) only beach samples.

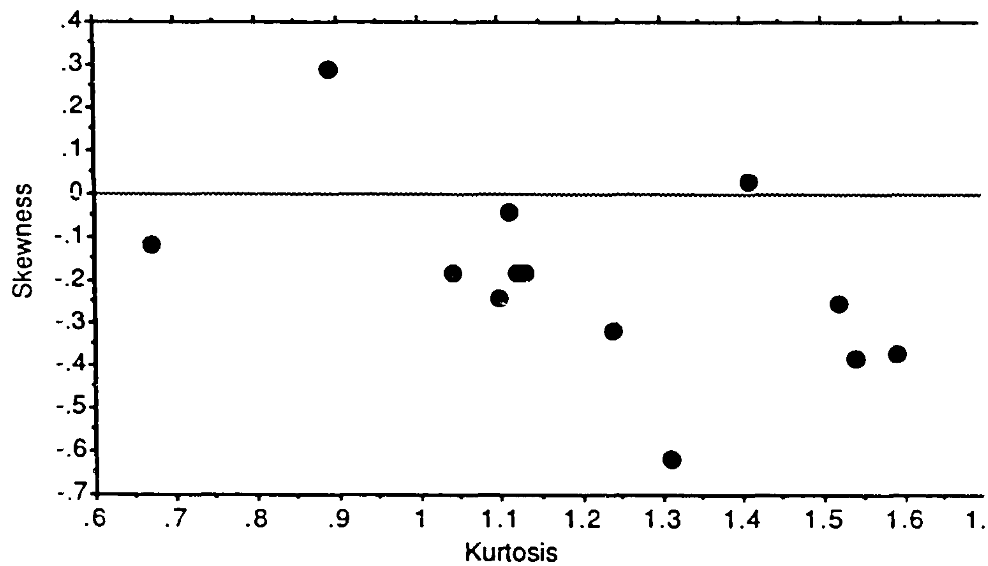

Fig. 2.22 b.

Fig. 2.22. Plot of Skewness in relation to Kurtosis in order to isolate beach from dune facies (a) all samples (b) only beach samples.

sands (2 to 3ø) cover the shelf for more than 50 km offshore in the area of the Shishmaref barrier islands, 50-100 km southwest of Espenberg. This distribution indicates that sand is being transported downdrift from offshore deposits near Shishmaref barriers to the Espenberg spit. The barrier island sands are very well sorted and have a mean of 2.38ø ±0.02 (Mason 1987a: Fig. 17 and unpublished data).

The Kitluk River bluffs, just updrift and west of the Espenberg spit, are undergoing erosion at present (J.W. Jordan1988). Intuition suggests that this updrift bluff erosion played a considerable role in spit construction downdrift. Unfortunately, I have only very limited grain size data and field observations on bluff sediments. I can only cautiously assess the possibility of bluff erosion. A sample collected by D.M. Hopkins (unpublished data) is coarse to medium silt: with a median of 5.5ø, but contains about 20% fine sand. This description matches my own field observations of the eroding bluffs which are composed of thaw lake, loess and tephraeous sediments. The beaches at the base of the cliffs consist of fine quartoze sand with some dark mineral, tephraeous, component. The mean of several Kitluk beach samples (n=4) is 2.14ø, fine sand (Mason, unpublished data). Fine sand, 2-3ø, is also reported 5 km offshore from the Kitluk coast (D.M. Hopkins, unpublished data). In general, the Kitluk beach sand differs from the bluff sediments and but closely resembles the barrier samples. Near river mouths, 2-3 m high dunes form at the base of the bluffs and sand is occasionally channeled upslope, forming low dunes over the bluff scarp.

The silt and clay fraction of the bluff deposits is eroded and transported by the longshore currents to the northeast toward Cape Espenberg and Kotzebue Sound. The silt fraction from the Espenberg nearshore zone is re-mobilized offshore into central Kotzebue Sound (Crager and McManus 1966:Fig.10). This silt plume appears on ERTS imagery (Sharma 1979:400ff) and on black and white aerial photos (Schaaf 1988a: frontspiece).

To estimate the relative contribution of various sand sources in the construction of Espenberg spit, I calculated the approximate volume of the 30 km long, 1-2 km wide Espenberg spit and compared this to an estimate of the sand content of the Kitluk bluffs (Table V). Assuming that the spit platform extends 5 m below MSL (inferred from offshore bathymetry) and the average thickness is 2 m above MSL, I estimate the total volume of the spit is about 278 million cubic meters. An additional 16 million cubic meters is added to account for the high dunes over the most recent ridges. The Kitluk bluffs, by contrast, extend for 20 km, with an average height of 5 m.

By using the extrapolated erosion rate of 2.24 km (0.56 per yr x 4000 yrs), I estimate a total eroded volume of 224 million cubic meters. This total must be reduced because the Kitluk bluffs contain a significant portion of ice, perhaps 25%, based on estimates from the North Slope (Reimnitz et al. 1988). Of the remaining 168 million cubic meters, only about 20% is sand; a total of 33 million cubic meters is available for longshore transport and eventual deposition at Espenberg. This fraction comprises about 11% of the total volume of sand at Espenberg; hence, about 89% must derive from offshore sands--the predominant source for building the Espenberg spit.

Granulometry and Depositional History

As described above, several grain size populations comprise the modern beach, with seasonal effects explaining the differences. The fine (2 -3 ø) quartz sand probably derives from the offshore sand bodies, described by Creager and McManus (1966). The slightly coarser sand consists of a dark mineral tephra and probably originates within bluff exposures between the west end of the Espenberg ridges and Kividluk and from the Kitluk River drainage. The dark, coarser tephra sand is deposited in discrete wedge-shaped beds and remains as a wind deflation lag deposit on the back- and mid-beach. Such coarser sands are subsequently transported further landward into the incipient dunes, during higher energy winter wind storms.

Specific Espenberg dune ridges landward of the modern beach are not distinguishable using statistic parameters because of the wide range of particle sizes within a single ridge. Sand strata interpreted as marine (ie., resembling the modern beach) contain coarser grain populations, with mean values between 1.7 to 2.2 ø. Such strata underlie ridges E-2, E-4, E-5, E-7, E-14, and E-20 at levels of 0.5-1.0 m above MSL. Dune facies within ridges become finer grained with distance from the sea (Fig. 2.17, 2.18). The most recent dune ridges E-1 to E-5 contain sand 2.0-2.2 ø in diameter while no dune samples that coarse were obtained from dune facies of ridges E-14 to E-20. However, both sand populations are found in the smooth, low ridges E-6 to E-12 considered to be deposited solely by storm surges with little dune contribution. Hence, it seems that a combination of eolian and marine dynamic processes are responsible for constructing all the ridges.

The coarser nature of the youngest ridges may be explained by several factors. Differing sediment sources may be involved; either a function of: (1) shifts in marine

The coarser nature of the youngest ridges may be explained by several factors. Differing sediment sources may be involved; either a function of: (1) shifts in marine sources due to increasing wave base reaching deeper, coarser deposits or (2) increased erosion of shore bluffs containing coarser sands or increased fluvial input of terrestrial sands. Both possibilities involve a difference in the storm-induced level of wave-energy ultimately responsible for forming the ridges at Espenberg. An increase in eustatic sea level may also be responsible for accelerating updrift erosion of bluffs and older Espenberg dunes (see above).

By comparing Espenberg granulometric data with stratigraphic observations, I find that the modern beach is composed principally of eroded dunes and bluff sediments. In terms of facies relationships, finer sand is found at the tops of ridges, as seen in ridge E-14. The most recent ridges are slightly coarser than older dune ridges and may reflect higher wind intensities or a higher erosion rate of coarse tephraeous bluff sediments. This distinction is important in understanding the depositional history of Cape Espenberg and the contextual evidence for Holcocene climatic change.

Holocene Depositional History of Cape Espenberg

Unit I: Rapid Progradation during 4000-ca. 3300 BP

Unit I consists of up to six berm and low dune-mantled ridges, attached to the mainland on the west and backed by a shallow lagoon of Kotzebue Sound to the southeast. In the A and B complexes, in the west, the Unit I ridges are welded to the mainland, but they formed as islands in the eastern C and E complexes (Fig. 2.5, 2.6). Unit I ridges in the C complex formed along a tidal channel flowing from the Espenberg River, emptying into a lagoon of Kotzebue Sound, as evident from a small subtidal delta (Fig. 2.5). A large tidal inlet, 1 km wide, formed between the C and E complexes and constructed a large flood tidal delta on the landward side; the D complex did not exist at the time (Fig. 2.6).

From a longitudinal perspective, Unit I is wider in the western complexes, especially the B complex, and records a coastal orientation trending about 15° to the southeast. This orientation differs from younger depositional units (ie., II to IV) in the

B complex which trend about 10° northeasterly. In the easternmost E complex, ridges in Unit I spread spoke-like to the southeast and swale width increases markedly, averaging 54 m (see below, Fig. 2.23). Although few of the eastern Unit I ridges have cross-cutting surge channels, large, polygonally-shaped lakes have developed within several of the wider swales. Some lakes flood neighboring swales and even inundate some of the ridges. The presence of multiple peat ramparts bordering some lakes show a progressive shrinkage in lake size.

Some of the earliest eastern Unit I ridges are as much as 5 m above MSL, but most are only 2 to 3 m above MSL. All the Unit I ridges are well drained and commonly have oxidized subsurface B soil horizons (see below). Overall, these pedogenic characteristics reflect a persistent down-profile percolation of groundwater, resulting in a homogeneous reddening of the sands with occasional tongues of coarser particles which delineate the process.

Unit I was truncated by the emplacement of Unit II, a younger aged single composite ridge, laterally traceable along the entirety of the Espenberg complex. In places, the younger Unit II dunes transgress Unit I. Along the southern, lagoonal shore of the E complex, the oldest portions of Unit I ridges are eroded, implying that the that the earliest deposits at Esepnberg may be better preserved under the surface of other complexes .

Stratigraphy

Well-developed soils occur throughout Unit I at Espenberg, in ridges with and without blowouts. Two laterally extensive, stratigraphically separated paleosols occur on the oldest E-20c ridge (Fig. 2.24). The lower paleosol (P_1) varies in elevation from 1.2 m to 3.0 m above MSL, delineating a former ground surface and pedogenetic activity (perhaps 50-70 cm) below it. Unweathered sand, up to 1.0 m thick, separates it from the upper paleosol (P_2), which lies about 1.0 m below the modern ridge surface at 5.0 m above MSL in places. Both paleosols alternate between (a) thin (<5 mm) laminae, composed of unaltered sand and (b) compact beds of silty sand, dark reddish brown (2.5YR 2.5/4) or dusky red (2.5YR 2.5/2) in color. This alternation reflects seasonal inputs of eolian sand over a stabilized vegetation cover. At one locality, over 24 discrete laminae were discerned in only a 10 cm thick unit, implying that eolian events were comparatively frequent but had a neglible impact on the vegetation.

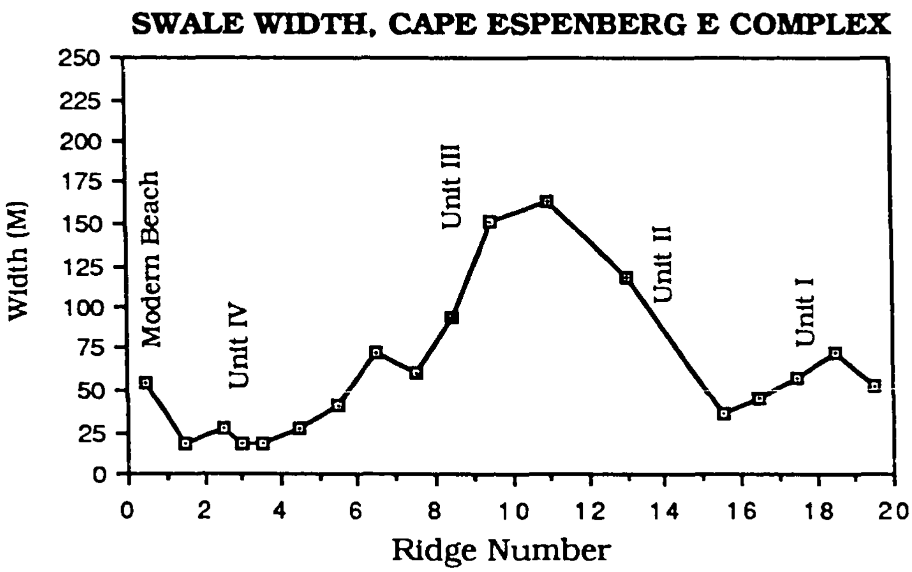

Fig. 2.23. Swale width across Cape Espenberg E complex. Swale width, the distance between ridges, provides a proxy measure of the storm recurrence interval. Swale width is greatest in Units I and III, indicating that storms occurred with less frequency during these periods.

The lowermost P_1 paleosol is deformed by involutions, small desiccation cracks and larger wedge structures infilled with younger sediments and organic fragments. The high number of wedge casts and convolute bedding in exposures on the ridge implies that a recurring process is involved--likely cryogenic in origin (Vandeberghe 1988), though seismic activity and/or soft-sediment deformation due to large mammal traffic is also possible (cf. Allen 1982).

Groundwater percolation has caused the breakdown and down-profile transport of iron compounds, ie. spodsolization. Tongues of downward transported dark mineral sands occur beneath the surface of smooth ridges and provide evidence of the spodsolization process (Fig. 2.25). Platy ferricrete soil horizons have formed in some areas of the paleosols; commonly where groundwater is discharged adjacent to an eroding channel bank. Ferricretes record seasonally dry conditions and a comparatively warm climate, as noted by Pye (1983b).

Dating: Tephra and Archaeological Sites

The initiation of beach ridge deposition at Espenberg is dated by a tephra within sediments of the oldest E-20c dune ridge. The tephra bed occurs within the lowermost P_1 paleosol, at heights varying from 1.0-3.5 m above MSL. The pale brown (10 YR 6/3) tephra is laterally continuous for over 300 m but is only 1.0-1.5 cm in thickness. Based on microprobe analysis, Riehle (1987, written communication) identifies this tephra as a distal facies of the widespread Alaska Peninsula Aniakchak eruption dated at numerous southwest Alaska localities between 4000 and 3400 yrs old (Miller and Smith 1987, Riehle et al. 1987).

A radiocarbon sample from a geological context provides an independent age estimate for the onset of deposition of Unit I and another estimate for the age of the Aniakchak tephra eruption. This sample of grass from a paleosol on the E-20a ridge yielded a ^{14}C data of 3700±90 BP (ß-23170) (2077 cal BC). The E-20a ridge is more landward and presumably younger than the tephra bearing ridge, providing an upper limiting age of 3900-3400 BP for the eruption, which is consistent with the other western Alaskan age estimates cited above.

Archaeological sites on Unit I ridges are scatters of culturally diagnostic lithic artifacts and manufacture debitage ascribed to the widespread Arctic Small Tool tradition (Giddings 1964, Giddings and Anderson 1986) (Table III). Some lithic scatters

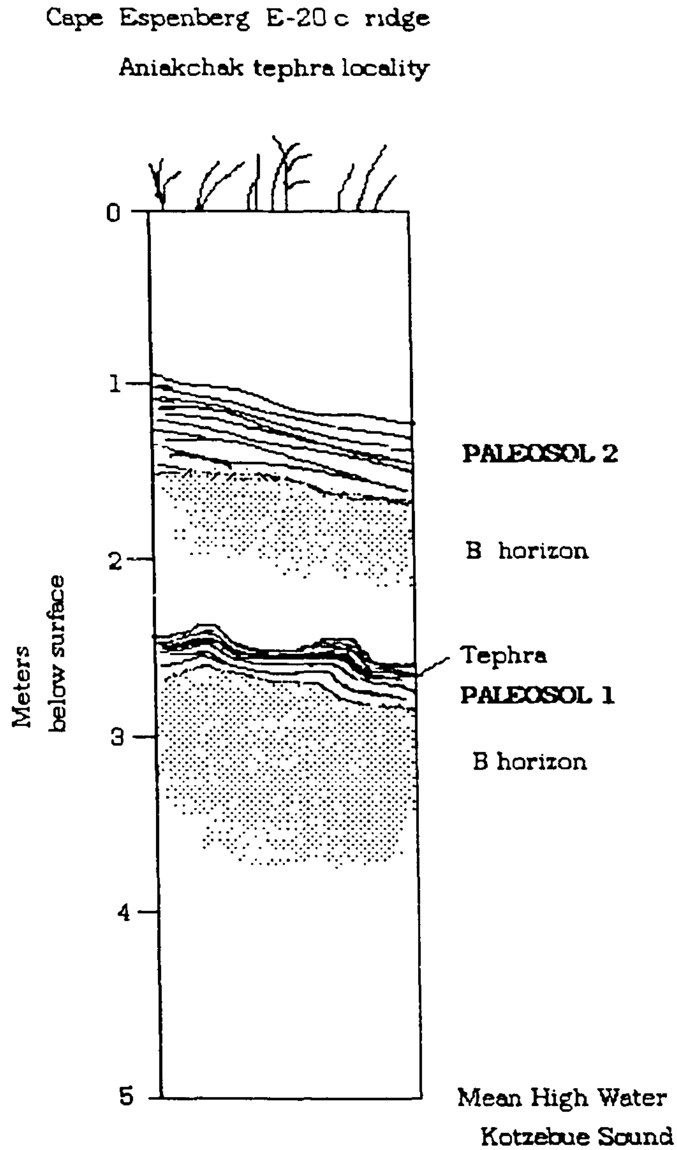

Fig. 2.24. Schematic Stratigraphic Profile from the oldest E-20 c ridge in Unit I, Cape Espenberg. The Aniakchak tephra bed found in the lower Paleosol P1, dates to ca. 4000-3400 BP, based on the work of Riehle et al. 1987. This age provides an independent age assigment for the onset of beach ridge sedimentation at Espenberg.

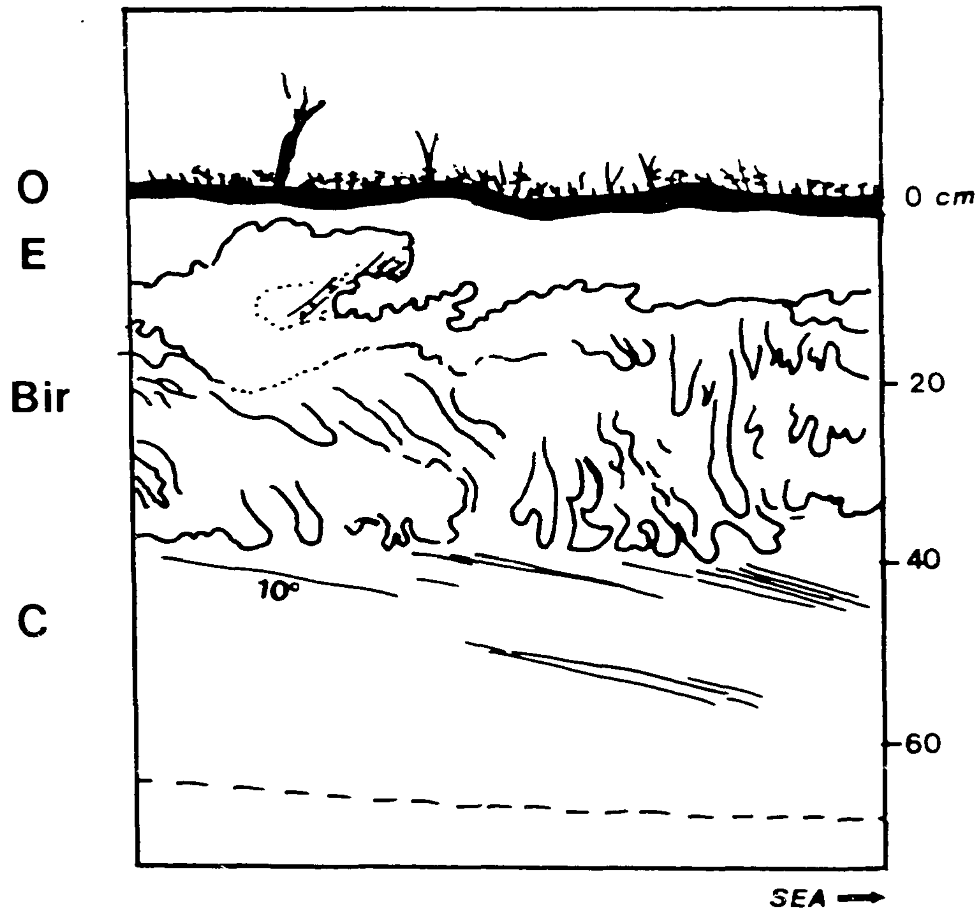

Fig. 2.25. Stratigraphic Profile, E-18 ridge, Unit I, Cape Espenberg E complex. A tongue of dark minerals delineates the process of spodsolization.

extend more than 75 meters (Mason 1989, field notes). The archaeological loci[4] of KTZ-122 and KTZ-124 are associated with a buried paleosol 35 cm below surface and with diagnostic ASTt tools (including a burinated biface) in blowouts on the surface of the C complex-12b ridge. An AMS assay on charcoal from the paleosol yielded a date of 3750±80 BP (ß-33758) or 2166 cal BC (Harritt 1990). Farther east on the E-18 ridge, a date of 3570±100 BP (ß-19643), or 1904 cal BC, was obtained from a charcoal concentration 12-21 cm below surface associated with culturally produced fire-cracked rock (Schaaf 1988b: 281). Both these dates provide an upper limiting date on the formation of the earliest ridges in Unit I.

Interpretation

The accretion of beach ridges along the Espenberg coast began as the beach widened at the base of the low bluffs in the westernmost A and B complexes. At this time, ca. 4000 yrs ago, in light of the differing northeastward orientation of the A and B ridges, the Kitluk River coast must have been less eroded than at present. In the C complex, the first beach ridges were added as a low tidal flat at the entrance to Kotzebue Sound while a tidal inlet was maintained between the Espenberg River and the lagoon to the south. The extent of Unit I tidal exchange in the C/E inlet is unclear because of latter increased tidal or storm inflow during Unit II.

For the most part lacking high dunes and separated by relatively wide swales, the ridges of Unit I record comparatively low energy wind and storm events linked to infrequent storm events. After beach ridge deposition, three distinct eolian pulses are recorded by the E-20c stratigraphy described above (Fig. 2.24): (1) an initial low dune-building event that produced deposits up to 3 m above MSL, capped by the P_1 paleosol followed by (2) a period of eolian activity and stabilization that produced the P_2 paleosol, and finally, (3) deposition of an uppermost overbluff dune constructed by winds that removed sand from the lagoon beach. The spodsolic lower P_1 paleosol suggests that warmer than modern temperatures prevailed 3900-3500 BP (2300-1900 cal BC).

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[4] In Alaska archaeological sites are designated in sequence of discovery by reference to 1:250,000 map quadrangle names, KTZ stands for Kotzebue. Site information is archived by the State Office of History and Archaeology in Anchorage

The dune-building in the eastern part of the complex after 3500 BP and may be a local effect, caused by high sediment input connected with proximity to the C/D/E tidal inlet and/or a brief period of stormy or windy conditions. Alternatively, the construction of the 5 m high E-20abc dune ridges may reflect the cumulative effects of episodic eolian events occurring throughout the last 4000-yrs, involving winds from the south. At present, southerly winds and high seas lead to wave undercutting of the E-20c ridge (as in a storm during August 1988) and could be followed by overbluff eolian deposition at this southern margin of the Espenberg spit.

High lake levels post-date ridge formation and are widespread in Unit I. Higher strandlines even cross-cut ridges. Some lakes emptied catastrophically, as evident from outlets draining south, away from the sea to the lagoon. An interval of high precipitation may explain this positive lake level fluctuation and may explain the intensity of groundwater percolation and soil formation on Unit I ridges.[5] All of these effects may be related to warmer climatic conditions in the fourth millennium BP.

Where Unit I ridges intersected tidal channels or rivers, slightly recurved ridges were produced. The flow of water through some of these inlets was considerable; some inlets are more than 1 km in width. Channel widths between Unit I ridges are much larger than modern channel widths. Inlet openings are maintained by tidal and/or storm energies (McGowen and Scott 1975, Bruun 1978). The intensity of tidal or storm energies in the D/E inlet may be gauged from the extensive flood tide delta deposited landward of the D/E channel where the channel empties into the lagoon and the offset this channel lends to more easterly ridges of Unit I. It appears that current strength through the inlets increased over time due to drastic sedimentation changes in the younger Unit II, which are related to a differing climatic regime.

Unit II: The Older, Choris/Norton Dunes, ca. 3300 to 2000 BP

Unit II delineates a single composite dune ridge, about 1.5 to 1.8 km from the modern shore which attains a height of up to 9.0 m above MSL in the eastern part of the Espenberg complex (Fig. 2.15). The Unit II ridge is laterally continuous and easily

[5] In one case, a now drained lake in Unit I connects with an opening in the younger Unit II and the filling of the lake may be related to a storm surge during Unit II times. A saline marker bed in the subsurface would confirm this hypothesis.

distinguished in most of the Espenberg sub-complexes (Fig. 2.6): B-9 = C-10 = E-14 (but is not present in the younger D complex, cf. below). The easternmost Unit II ridge, E-14, divides into three individual sub-ridges to the southeast, reflecting the processes of berm ridge addition near an inlet mouth (*sensu* Hine 1979 described above).

Localized areas on the Unit II C-10 and E-14 ridges have undergone several episodes of blowout evolution which has produced interconnected basins laterally continuous for over 300 m. As many as four buried organic horizons or incipient paleosols are traceable in the deepest blowout basins. Many blowout basins contain ponds, while others show evidence of seasonal ponding--inferred on the basis of hygrophilic species such as rushes (*Juncus* spp.). Seasonal dessication of these ponds produces a characteristic subsurface mottling due to oxidation of the iron-rich sands.

In many places, the Unit II/I contact is vague and a transgressive dune front associated with the Unit II ridge is superimposed on older Unit I ridges. In terms of width, the Unit II increases considerably to the east, doubling to about 150 m.

Stratigraphy and Dating

(a) Stratigraphy Revealed in Natural Exposures

A cutbank on the east end of the Espenberg spit permits a subdivision of the E-14a ridge into a sequence of six events, based on differences in sedimentary structures, soil development and organic content (Fig. 2.26). A possible marine facies with markedly coarser grain size and inclined bedding (see above) was observed about 75 m west of the profile (on ridge E-14b), but was not observed in the profile described in Fig. 2.26. The earliest dune sedimentation, level*(a)*, consisted of sub-horizontal layers of grass separated by thin (<1cm) sand beds. A ^{14}C assay on the upper portion of the bed yielded a date of 1640±80 BP (ß-23171) (calibrated to 411 AD). The low dune formed by unit a was capped by a paleosol, level*(b)*, containing silt and comminuted organic fragments. The paleosol complex contains three sub-horizons, separated by unmodified, unbedded sand. The paleosol, level (b), is markedly deformed by subsequent events (Little Ice Age?) which produced nearly vertical convolutions. Loading and de-watering structures are common within the higher *level* c. By contrast, the most recent eolian *levels (d-e-f)* on the E-14 ridge record only the accretion of weakly laminated root bound sand.

(b) Archaeological Sites

Parts of the E-14 ridge have a hummocky topography resulting from successive cycles of blowout erosion. Blowout settings facilitated the discovery of archaeological sites, with over 40 site loci reported within a 2 km long portion of the ridge (Schaaf 1988a). All the archaeological loci located by Schaaf (1988a, b) or myself (Mason 1987, field notes) from E-14 blowout sites are Choris or Norton cultural manifestations, characterized by linear or check-stamped ceramics and bifacial lithics (Table III). Archaeological radiocarbon dates from four sites on E-14 provide an upper, minimum age estimate for the formation of Unit II: between 2660±110 (ß-17961) and 2285±90 BP ß-17968) (Schaaf 1988b). Using the two sigma value, this date range is 2880-2000 BP, calibrated to 1040 BC-200 BC (Table II-g). Two ^{14}C age estimates on the C-10 ridge (=E-14 equivalent) are slightly older, falling at 2790±80 (ß-33759) and 2530±130 BP (ß-33760) (Harritt 1990). These dates were run on archaeological charcoal embedded within a paleosol at the KTZ-127 site (Schaaf 1988b, Mason 1989, field notes). A ^{14}C sample on the western B-9 ridge yielded a date of 2850 ±70 BP (ß-17972); however this date is from charred, sea mammal oil cemented sand and requires a 400 yr correction for old carbon contamination (Mason and Ludwig in press, this volume, Appendix). The Espenberg ^{14}C range from Unit II falls within the range for other Choris and Norton sites along the Alaskan coast (Ackerman 1982, Giddings and Anderson 1986, Anderson 1988).

Interpretation

The scarped contact of Unit II with the older Unit I indicates that portions of Unit I were eroded prior to the dune formation event(s) that produced Unit II (Fig. 2.27). The storms that scarped Unit I occurred after 3400 BP and yet before 3000 BP, when the first people settled on the Unit II ridges. Then, intermittently, over several hundred years, during 3000-2000 BP, marine hunters of the Choris and Norton cultures settled on the Unit II ridges (B-9, C-10 and E-14). This fact suggests that the comparatively narrow, 50-150 m wide, E-14 ridge remained close to the sea for a considerable time. Though Unit II was primarily erosional, several discrete periods of dune building are represented by the easternmost sub-ridges E-14abc (Fig. 2.16). In summary, the E-14

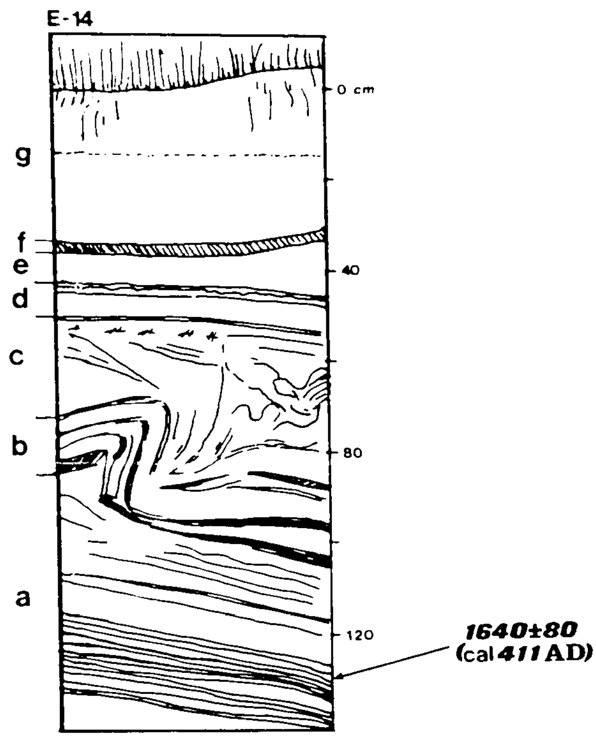


Fig. 2.26. Stratigraphic Profile of E-14 ridge, Unit II, Cape Espenberg. Depositional units labelled using small letters (see text). The paleosol layer, severely convoluted, post dates 411 AD. The convolutions probably reflect climatic conditions during the Little Ice Age, 1500-1800 AD.

ridges represent a composite of storm erosional events which truncated and scarped the earlier Unit I, followed by the addition of overbluff dunes atop the eroded scarp (Fig. 2.27). Some of the eroded sand was transported downdrift and built high dune ridges closer to the Cape.

The co-occurrence of several Unit II archaeological loci with paleosols provides an important reference point for interpreting climatic history. Accepting the fact that these buried organic (O) horizons represent a stabilized vegetation cover without sand transport leads to the conclusion that either higher summer or autumn precipitation and/or lessened winter wind intensity occurred at the time of the Choris and Norton occupations. Quite likely, higher precipitation is the causative factor, in light of the predominantly erosional cast of Unit II times.

Unit III: Rapid Beach Ridge Progradation, 2000-1200 BP

A drastically different balance between marine and eolian sedimentary processes prevailed after 2000 BP (ca. cal 200 BC). Unit III records the emplacement of low ridges (1-2 m above MSL) separated by wide swales, up to 200 m in width (Fig. 2.23, 2.27). Unit III has a width of about 1.2 km and represents over half of the total progradation at Espenberg (Fig. 2.15). Several ridges have a cover of low dunes (up to 3 m above MSL) and blowouts which expose two buried organic horizons. For the most part, Unit III ridges are extremely flat, but some areas contain shallow basins (< 50 cm deep), possibly the traces of healed blowouts. Swales fill with water perched by permafrost and blocked from draining by rows of palsas.

Palsas are most extensive in the more low-lying eastern E complex. Most palsas are of the string form (Seppälä 1988:255) and run across the surface gradient which drains to the southeast. Permafrost occurs about 70-80 cm below surface. Frost cracks in Unit III form a rectilinear network readily apparent on aerial photos (Figs. 2.16; 2.26). Frost cracks are adjoined by pairs of upturned peat ramparts which crosscut swales and lead to the formation of extensive lakes and ponds by impeding drainage. Some of the largest lakes are up to several km long. The history of lake development is complex and increased areas of freshwater ultimately follow the development and degradation of peat, as in Finland (Hopkins 1986, unpublished notes, Seppälä and Koutaniemi 1985).

Fig. 2.27. Aerial Photograph showing the contact between Units I, II and III at Cape Espenberg. This contact (Unit I/ II) is a scarp eroded by large storms dated to ca. 3300-3000 BP. Subsequently, overbluff dunes covered the scarp, forming Unit II.

Inlet filling and the formation of a large tidal flat also occurred during Unit III. As mentioned above, a 1 km wide inlet separates the C and E complexes (Fig. 2.6). This inlet remained open during Unit II times (3300-2000 BP), maintained by repeated high magnitude storm surges through the channel which deposited a flood tide delta. During Unit III the inlet filled, reflected by recurved ridges on both sides of the former inlet. A large 2 km wide tidal flat, the D complex (between the C and E complexes), may have resembled similar modern tidal flats within surge channels on the Shishmaref barrier islands, 50 km to the southwest. Another tidal flat area is present at the farthest east portion of Unit III, seaward from the E-8 ridges.

Incipient soils are common on most Unit III ridges, though buried organic horizons occur only on the low dune ridges E-8 and E-12. On the other smooth ridges, a darker epipedon about 3-5 cm thick commonly occurs near the surface, with an occasional thin leached horizon grading to slightly oxidized sands with depth, extending to water table at about 70 cm below surface.

Stratigraphy

On the smooth E-7 ridge, five pedogenic horizons are distinguishable above the 60 cm deep water table (Fig. 2.28). The five to eight cm thick surface O horizon consists of silty organic stained, rootlet-bound fine sand (10yr 2/2, very dark brown). The lower A-B horizons (10 to 30 cm below surface) are marked by vague, gradational contacts reflecting a slight degree of oxidation of the parent fine sand, the C horizon, at depths of >40 cm below ridge surface. Dark mineral sands in the unweathered C horizon reveal faint seaward inclined (5°-7°) bedding.

Dating and Archaeological Sites

Few archaeological remains are reported from Unit III ridges. Partly this is a reflection of the comparative scarcity of blowouts on the very low, flat ridges. However, no sites were found on ridge E-12 which does contain numerous blowouts. Several extensive but diffuse scatters of lithic artifacts were found in blowouts from the E-8 ridge. Giddings found square house depressions outlined by crowberry growth (termed "moss" by Giddings) on the E-8 ridge (Giddings and Anderson 1986:24). At the KTZ-157 site, Harritt's (1989) excavations in an crowberry-outlined house depression and nearby surface collections produced artifacts diagnostic of the Ipiutak culture (Larsen and Rainey 1948, Giddings and Anderson 1986). Archaeological charcoal yielded dates of 1400-1300 BP (calibrated weighted average: 1358±41 BP or 657 AD (Table II-(g), Harritt 1989). These dates provide an upper limiting age for deposition of the middle of Unit III. The dating of Unit III is otherwise constrained by date estimates on the adjoining depositional Units II, older than 2000 BP, and Unit IV, younger than 1200 BP (see below).

Interpretation

The Unit III ridges are primarily berm ridges formed by swash action (*sensu* Hine 1979), during the recovery phase after storm-induced high water levels. Unit III shows that a sudden change in sedimentation regime occurred between 2000 and 1200 BP with the intermittent progradation of berm ridges separated by wide swales, only occasionally building low dunes. Dune building may have been minimized by low intensity winds. This comparative ridge stability favored heaths and shrubs but excluded burial tolerant and dune-building grasses. The formation of the string bogs and palsas reflects circumstances with little snowcover and substantial penetration of frost, producing a perched water table. Since palsa formation requires the prior formation of peat, it must post-date ridge formation.

The large width of swales (Figs. 2.23, 2.27) indicates that the storm recurrence interval was long, because swales reflect deposition unrelated to storms (Hayes and Boothroyd 1969, Davis et al. 1972). Hence, few *major* erosive storms occurred between 2000 and 1200 BP, though minor storm surges did occur, at a frequency of about two per century (a 50 yr recurrence interval), a calculation derived from dividing estimated 800-yr duration of Unit III by the total number of ridge fragments (n=16) .

The low dunes on E-12 and E-8 ridges are anomalous, implying that slightly different wind or storm conditions prevailed, in contrast to earlier or later periods. Yet, the presence of Ipiutak houses on one of these ridges supports the interpretation that storm surges were still less frequent or intense because the danger of storm overwash must have been an obvious consideration for coastal populations.

The C/E inlet was filled during the period of time represented by Unit III as described above. This inlet closure resulted as fewer and less frequent storms passed through the inlet and low dunes built. Few large storms interrupted this infilling

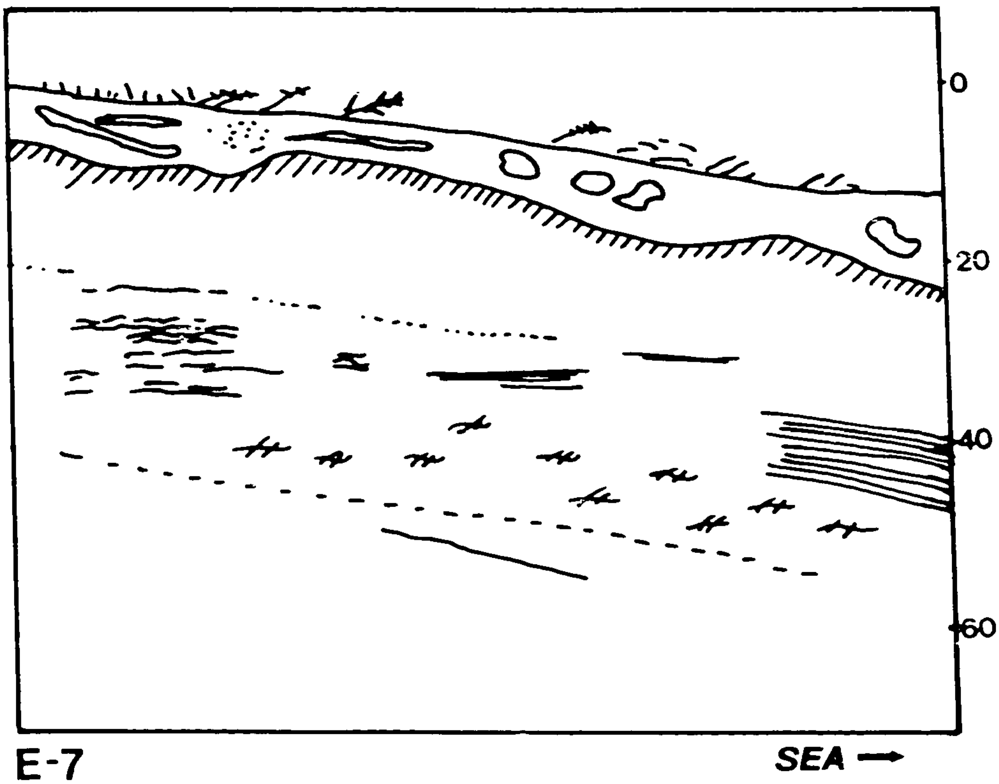


Fig. 2.28. Stratigraphic Profile of E-7 ridge, Unit III, Cape Espenberg. Only very slight soil development occurs in this ridge, marked by vague color differences down profile.

process which supports the idea that longshore transport dominated depositional processes more than channel cutting of storm surges. This addition of sediment into the longshore system which produced the adjoining tidal flat (the D complex) probably owes its origin to massive updrift erosion during the preceding period, 3300-2000 BP. During the stormy interval of Unit II times, some of the sand was stored offshore.

A former tidal flat area also occurs to northeast of ridge E-8, a in a wide swale between E6/E8. This tidal flat is younger or contemporary with the KTZ-157 archaeological site on E-8, dated to about 1400-1300 BP. The E6/E8 tidal flat may have resembled the modern flats to the east and south of the Cape. Such tidal flats are related to updrift erosion and a temporary surplus of sediment in the longshore transport system. Presumably, this erosive event occurred at the start of Unit IV.

Unit IV: The Younger, Thule Dunes, the Last Millennium

The youngest beach ridges at Espenberg differ substantially from the rest of the deposits. Unit IV has a minimum of two to three laterally continuous dune ridges that extend vertically up to 20 m above MSL in the western portion of the B complex but decline to 3-5 m above MSL in the east, near the Cape. The highest dune ridges in the B complex record a period of extensive localized erosion and re-deposition, due to storm surge erosion of niches followed by overbluff dune deposition, as in Scotland (Ritchie 1972). For the most part, the youngest dune ridges (incipient dunes) near the backbeach are bound by beach grass (*Elymus arenarius*), whose presence is instrumental in building dune-ridges (Ranwell 1972, Chapman 1976, cf. Mason this volume, ch. 3).

The vertical growth of dunes of Unit IV overwhelms the older Unit III ridges and blocks many of the older surge channels. The oldest unit IV ridge, E-5, transgresses older unit III ridges very abruptly (Figs. 2.5, 2.6, 2.16). The timing of this transgressive event is estimated at 1300-1100 BP, based on samples from both archaeological samples and surficially collected shells, calibrated for reservoir effects (Table II-g).

Many of the dune ridges of Unit IV are pitted by blowouts, which are more developed with distance from the modern beach. Lakes and ponds occur in most of the swales of Unit IV ridges, swales lack palsas and frost cracks. Ponds are increasingly large with distance landward, with the largest--about 1 km in length--formed between E-4 and E-5 ridges.

The depositional history of Unit IV is further complicated by several major erosional events recorded as abrupt scarps. The scarps are most clearly defined at the D/E inlet margin on the E-3 and E-2/E-1 ridges and record widespread storm surges. Sediment eroded and re-deposited downdrift during these surges was later re-worked into incipient dunes at the base of the eroded scarp.

Stratigraphy and Dating

A cutbank exposure at the eastern end of the Cape Espenberg spit reveals the predominately eolian character of ridge construction (Fig. 2.29). The E-5 ridge rises 4 to 6 m above MSL (decreasing in elevation northwest to southeast) and has a width of 50 to 70 m. An upper limiting age of the E-5 ridge is provided by buried archeological remains at KTZ-87, located on the crest of the E-5 ridge, which is 3 m above MSL (Harritt 1989). Two charcoal ^{14}C dates from a component 86 cm below surface are in the range of 790±70 BP (ß-28008) and 720±70 BP (ß-28009) (calib. at 1257-1279 AD); a third sample provided an assay of 1020±120 yrs. BP (ß-28007) (999 cal AD). Hence, ridge E-5, the earliest of the Unit IV ridges, formed before 800 BP (1200 cal AD) and perhaps earlier than 1000 BP (1000 cal AD).

Another estimate for the onset of Unit IV is provided by the archaeological site KTZ-115, on the more westerly C4/5 complex ridges, 10 km northwest of the Cape site, KTZ-87. The KTZ-115 site has an exhumed paleosol dated to 1010±90 BP (ß-17969) (cal 1015 AD), concordant with the date of ca. 1000 AD near the Cape. Further, the C-4/5 paleosol is within the basin of a blowout only about 2 m above MSL, topographically lower but not necessarily stratigraphically lower than the sample below the crest of the more easterly 3.5 m high E-5 ridge. Hence, the C4/5 date may be closer to the actual time of ridge formation. The 200 yr older date from KTZ-87 in the E complex could have resulted from erosion updrift from C complex dunes. As hypothesized above, updrift dune erosion/ downdrift re-deposition evidently proceeds in a stepwise manner west to east across the complex.

Unlike some of the dune ridges, the sand in the E-5 exposure is not impregnated by discrete beds of grass or rootlets. At the base of the exposure, several cycles of steeply cross-bedded laminae (30°) are capped by 2 cm thick near-horizontal (2°) beds rich in medium to coarse sands and shell debris (Fig. 2.29). Such stratigraphy is typical of berm ridges on the modern beach (Fig. 2.13) and reflects deposition during the waning phases of storms. Shell-rich beds are absent higher in the section. The height of these shell and coarse beds extends from 50 cm above MSL to 1.2 m above MSL.

The basal unit a formed by the berm ridges on E-5 provided a nucleus, or a platform upon which incipient dunes were able to form (unit b). Exposures at the cutbank at the margin of Espenberg spit show that two to three discrete berm ridges underlie the E-5 ridge (Fig. 2.29). In profile, the superimposed incipient dunes are marked by inclined (10°-18°) thin laminae, often only several mm in thickness and discontinuous over distances of greater than 10 cm. Truncation surfaces are apparent, recording temporary pauses in sedimentation. Micro-scale differences in sedimentation produce alternations in cross- or plan-bedding or massive beds dominated by coarser particles (McKee and Bigarella 1972, Bigarella 1975).

Above the sand beds representing low dunes atop the berm ridge, the character of the sedimentary units becomes more tabular and horizontally extensive beds (units c) transgress landward filling former inter-ridge swales . In several places, ice wedge casts (Fig. 2..29) are apparent within the middle units of the E-5 (unit d). Sedimentary structures within the wedges differ from surrounding beds which are disrupted by the wedge. Instead, the wedge is filled with loosely bound rootlets and flame structures, indicators of inward directed grain-flow. The down-turned strata of these features resemble the linear troughs cross-cutting the surface of the ridge. Though no ice was found associated, the wedge structures presumably reflect cryogenic processes, syngenetic with the formation of the dunes.

Archaeological Sites and Chronology of Ridge Formation

Archaeological loci are particularly common on Unit IV ridges and consist of numerous clusters of house depressions and lithic and ceramic scatters of Birnirk, western Thule and old Kotzebue cultures (Giddings 1952, Giddings and Anderson 1986, Schaaf 1988a, 1988b, Harritt 1989). Clusters of houses are preferentially located adjacent to relict and/or active drainage margins. Detailed, reconnaissance level excavations at three sites on ridges E-5, E-4 and E-2, near the Cape, provide a suite of radiometric dates that closely bracket the upper age for three of the ridges (Harritt 1989). The series of 15 dates reveals two principal occupation periods; for E5/4: 700-600 BP and for E-2: 300-200 cal BP (Table II-g). However, viewing the dates plotted with

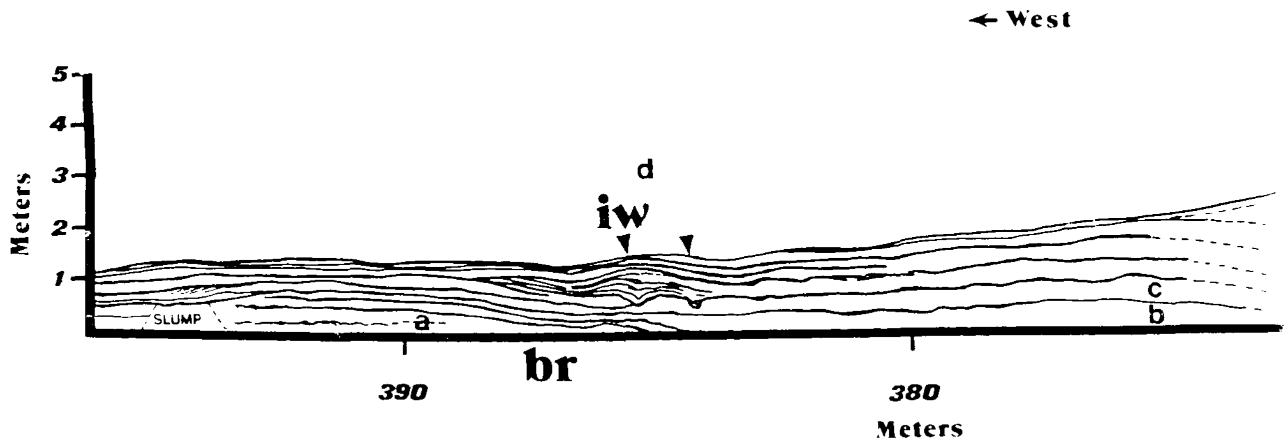
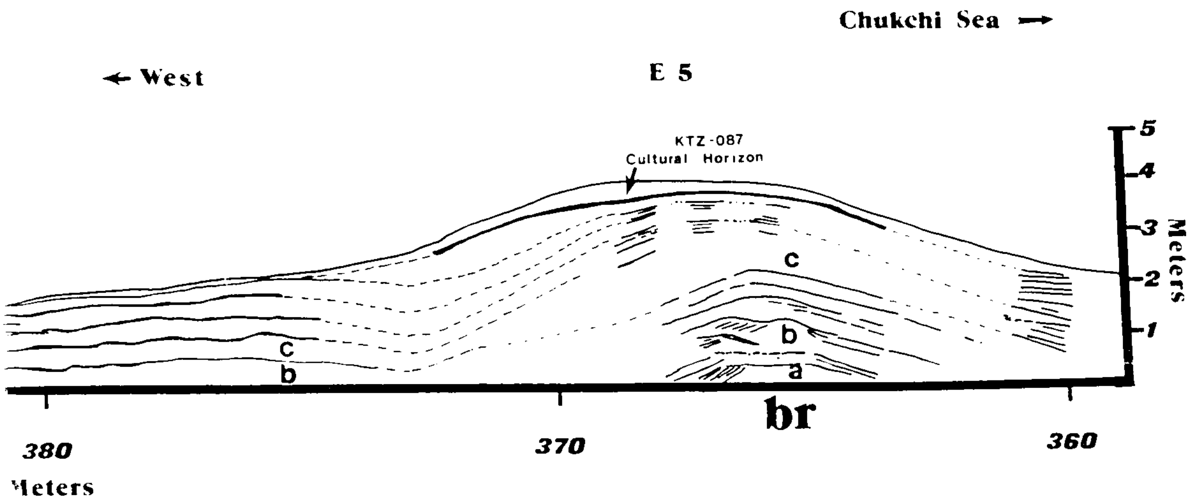


Fig. 2.29. Stratigraphic profile of E-5 ridge cutbank at Cape Espenberg eastern margin. Note presence of ice wedge casts (IW). The dune originated as a series of smaller berm ridges (BR). Radiocarbon dates from the archeological site KTZ-87 provide an upper limiting age of 1200-1290 AD for the building of this ridge.



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a two sigma range, considerable overlap is observable (Fig. 2.14b). While E-5 and E-4 clearly were occupied at an earlier time than E-2, these high ridges continued to attract inhabitants for some time after lower, more seaward ridges had been added. Age estimates on two sites (KTZ-69 and KTZ-130), 3 to 10 km west of Cape Espenberg, indicate that the E-3ab dune ridges formed before 590±90 (ß-17965) (cal 1351 AD) and 500±80 (ß-17969) (cal 1422 AD), an age slightly younger than E-4 but older than E-2.

The large swale between E-3 and E-2 indicates a pause in dune formation. Dune building started again before 247±33 BP (or 1656 cal AD), averaging a series (n=4) of dates from KTZ-101, located on the E-2c ridge. A swale of about 30 m width separates E-2 from E-1 towards the Cape, though in more western locations the E-1 ridge overtops the older E-2 ridge. The most recent 6 m high E-1 ridge contains only late prehistoric and post-contact settlements less than 200 yrs old. The formation of the E-1 ridge must post-date 1700 AD and precede 1900 AD. A laterally continuous scarp along the lower third of the E-1 ridge reflects recent 20th century storm erosion.

The most recent, post-1900 AD, incipient dunes vary widely; although most locations have two *incipient* dunes in the back beach. However, about 1-2 km east of the D/E inlet, about four incipient dunes (less than 2 m above MSL) lie seaward of a 5 m high dune containing undated late prehistoric/early modern house remains (Mason 1987, 1988 field notes). This variable growth of incipient dunes also reflects the stepwise erosion of dunes coupled with and downdrift dune building.

Interpretation

As mentioned above, archaeological wood charcoal establishes that the onset of Unit IV was between 1300 to 1100 yrs ago. However, a time lag effect due to the use of wood may be biasing the record. Two considerations are important: (1) the 200-250 yr lag introduced in dating long-lived tree species (Taylor 1987) and (2) a transportation lag of 30-35 yrs resulting as driftwood is carried by ocean currents from its upriver sources; the Yukon, Anadyr and other rivers (Giddings 1941:80ff,1952). Thus, the true age of Espenberg ridge formation could be considerably younger, altering the chronological interpretations presented above. However, the use of short-lived grass as a dating material by J.W. Jordan (1990) and myself in our geological research provides a supplemental source of chronological data (Table II-f). J.W. Jordan (1990) obtained a ^{14}C assay of 980±70 (ß-33551) BP from the base of the highest dune on the Shismaref barrier islands--a parallel depositional setting to my Unit IV or Younger Dunes. Dates on surficial shell from E-5 also fall ca. 1100 BP after correcting for reservoir effects (Table II-g). It seems, therefore, that no appreciable lag time exists for driftwood used by prehistoric peoples on or near Espenberg.

The two sets of dates (ca. 1000 and 700 BP) appear to reflect the two stage depositional history evident in the E-5 cutbank (Fig. 2.29). The E-5 ridges formed as a result of large storms (1) about 950-1000 AD and (2) before 1250 AD, contributing the bulk of the wind energy to mobilize sand. Cryogenic activity resulting in deformation of strata occurred subsequent to the formation of the ridge, probably during the Little Ice Age (ie., 1500-1800 AD). Deformation of older strata on the Unit II E-14 ridge also occurred during the Little Ice Age (Fig. 2.26).

The scarps on ridges E-5 and E-3 indicate widespread erosion related to storm surges and are tentatively dated to after 600-500 BP before 300-200 BP respectively, based on up- and down-drift archaeological sites on those ridges. Erosional events producing scarps should correlate with ridge building downdrift, as is confirmed by examining the chronology of dune building and stasis represented by the development of swales.

Variations in swale width reflect the period between storm surges, as described above. A swale of 30-50 m width separates the 1000-600 yr old E-5 ridge from the E-4 ridge; however, both contain dated archaeological sites nearly contemporary: 700-600 BP (or 1200-1300 cal AD). Thus, although the E-5 ridge must have built prior to the occupation on the younger E-4 ridge, the archaeological dates provide no further resolution of the chronology. Perhaps purely cultural considerations related to resource availability (other, more productive places to seal) or population pressure are involved in the location of settlements. A dune building event during 600-500 BP (1350-1450 cal AD) is recorded by sites on ridge E-3 followed by period of stasis, marked by an absence of dunes, the 40-50 m wide E2/3 swale. In the last 400 yrs, two principal dunes have built at Cape Espenberg; one before 1600 AD and one after 1700 but before 1900 AD. In places the most seaward dune, E-1, transgresses the older E-2 ridges.

In summary, Unit IV at Cape Espenberg reflects several pulses of eolian activity in the wake of massive storms, associated with regional and global climatic variability. As estimated by calibrated archaeological limiting dates, the principal periods of heightened storm activity at Espenberg are :

(a) after 1000, but before 1200 AD;

(b) 1300-1400 AD;
(c) before 1600 AD; and
(d) after 1700 AD but before 1900 AD.

Climatic Factors Affecting Beach Ridge Formation during the last 1000 years

To gain insight into possible climatic controls on ridge formation during the last 1000 yrs, I use proxy records from East Asia and Alaska. My rationale in using historic records from East Asia is based on the upper atmosphere teleconnection between East Asian and western Alaskan weather. This interrelation derives from Rossby (horizontally propagating) wave fluctuations which determine the position of the Okhotsk and Aleutian pressure fields (Okawa 1974, Wang and Zhao 1981, Lough et al. 1987). Modern studies of synoptic meteorology can provide analogs of past conditions (Bao 1987). Studies show that anomalous April dust storms in north China are linked to outbreaks of cold Siberian air masses which eventually decay in the Bering Strait region (Liu et al. 1981, Liu et al. 1989, NOAA 1981, 1983). Such weather systems generate winds capable of moving sand from the beach to form dunes, as was the case during 1988 (Mason 1988, field notes). Similarly, in the fall, North Pacific typhoons occasionally reach the Bering Sea and generate surges of up to 7 m above MSL, as in 1974 (Wise et al. 1981). By contrast, warm, stable August conditions over the Chukchi Sea may be connected with the El Niño sea surface temperature anomalies in the eastern Pacific (Huang and Wu 1989:29).

In view of these relationships, Chinese records (Fig. 2.30) should provide a useful climatic framework for interpreting beach and dune ridge formation at Espenberg. Anomalous winter thunderstorms near Beijing are correlated with cold temperatures and are associated with intensified high pressure in eastern Siberia. Winter thunderstorm activity peaks at 1100-1300, 1350-1400, 1450-1550 and from 1600-1900 AD (Wang 1980) (Fig. 2.30c). Periods of intense dust fall are also linked with cold climatic phases, as during the modern synoptic setting. Intense dust falls occur with greatest frequency (Fig. 2.30b) at 500-600, 1150-1250, 1450-1550 and 1610-1690 and 1840-1880 AD (Zhang 1984). Heightened winter winds occur in China precisely during the time intervals of Espenberg dune ridge formation within Unit IV, suggesting a direct connection (Fig. 2.30a).

Proxy records of decreased temperatures are also available from Greenland ice cores. Dansgaard et al. (1975) describe periods of $\partial^{18}O$ cold-related anomalies at 680-700, 810-860, 1000-1100, 1150-1200, 1290-1310, 1325-1390, 1420-1510 and 1720-1780 AD. Dune construction at Espenberg co-occurs with some of these cold anomalies (Fig. 2.30a).

To obtain proxy measures of summer temperature and precipitation tree-ring widths (Fritts 1976) are useful, if coupled with studies of growth/ring correlations (Garfinkel and Brubaker 1980). Giddings (1948) assembled a 1000 yr tree-ring chronology for the Kobuk River, based on archaeological samples. Since such samples may be masking local edaphic effects (Fritts 1976), the Kobuk record should be used with caution.

A preliminary, unfiltered plot of Giddings' (1948) data is useful in identifying deviations from mean ring width (Fig. 2.31). Drastic year to year oscillations in tree-ring width, range from over 1.5-2.5 times the mean to less than half the mean ring width. Widely variable oscillations occur during discrete periods, 1000-1080 AD, 1360 AD and 1520-1560 AD. By contrast, lengthy intervals show moderate conditions, with all rings within 20% of the mean. Such equitable periods fall at 1170-1270, 1310-1340, 1450-1500 A.D.

Increased growth, ie. wide tree-ring widths, may be linked to increased storm activity ("low pressure departures") in the North Pacific, based on the work of Blasing and Fritts (1975:51). Heightened storm activity--increased precipitation--may supplement the water balance of some species. The timing of this increase in storminess is crucial to understanding coastal erosion patterns. Summer or fall storms may produce a substantial rise (+0.5-1.50 m) in water levels which can lead to significant beach erosion and re-distribution onshore downdrift (J.W. Jordan 1990). Warmer conditions may result from stable atmospheric conditions during July-August or an extension of the warm period into autumn. As noted by Garfinkel and Brubaker (1980), high temperatures in autumn often lead to wider rings.

Chinese flood records provide a similar record of summer storm frequencies influenced by the North Pacific sea surface temperature and air pressure anomalies. Wang and Zhao (1981:279) report widespread flooding in north China during 1510-1580 AD, a period of high growth anomalies in the lower Kobuk of northwest Alaska. A similarco-occurrence between China and northwest Alaska is documented for other decadal periods, especially 1000-1030 AD (Wang et al. 1987).

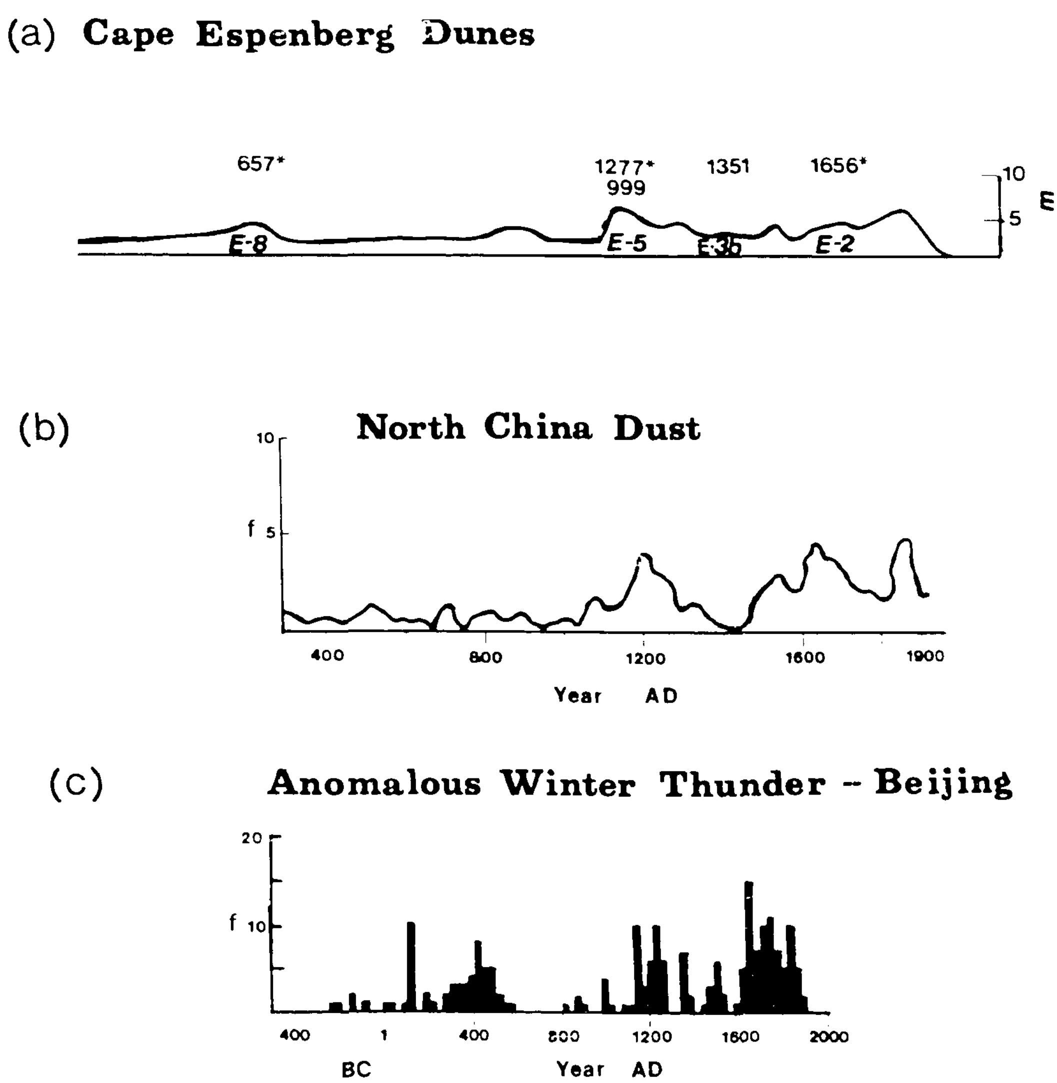
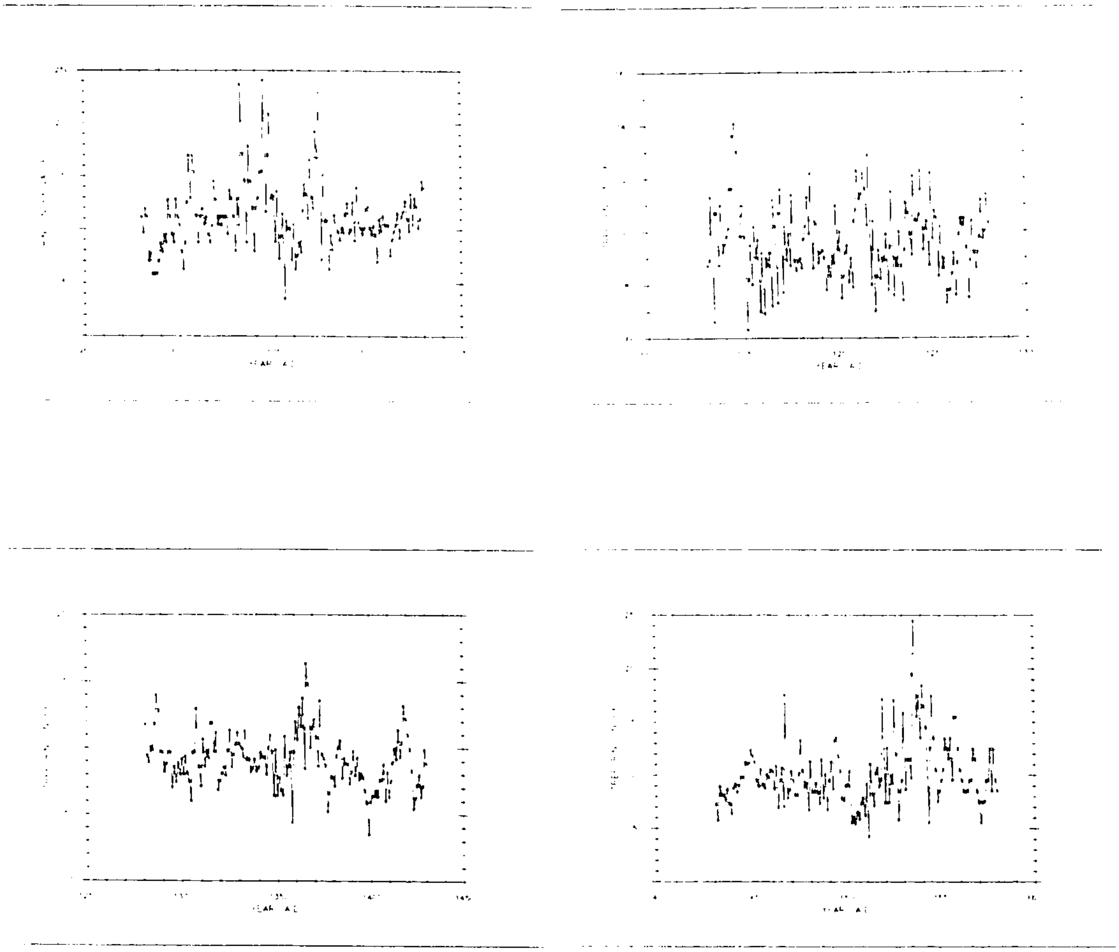


Fig. 2.30. Temporal correlations between Cape Espenberg dune formation (a), and the frequency of dust fall (b) and anomalous winter thunderstorms (c) in north China. For Espenberg, the topographic outline of the dunes is presented in meters above mean sea level. The date above the ridge is an average of several calibrated radiocarbon assays presented in Table II-g. The Chinese data, from Wang (1980) and Zhang (1984) is a frequency (f) plot of storms as recorded by historians. Both thunderstorms and dust falls are related to outbreaks of Siberian air across China (cf. Bao 1987).



Note Scale Differences

Fig. 2.31. An unfiltered plot of tree-ring widths measured by Giddings' (1948) for samples from the lower Kobuk River area, northwest Alaska. A single tree from archaeological context provides the early part of the record. Despite this limitation, the tree-ring data indicates that the period ca. 1000-1100 AD was one of extreme positive and negative oscillations in precipitation and probably of storminess. This period correlates with the time of formation of the Espenberg ridges.

In summary, the building of dune ridges at Espenberg during the past 500-1000 yrs requries a combination of climatic conditions. By refering to dendroclimatological and historic reconstructions, I offer the following scenario: heightened summer and/or fall storms favored erosion and the re-distribution of sand onto the back beach. Intensified winter winds led to transport of sand from the back beach into adjacent incipient, grass bound dunes which accreted vertically. During the succeeding 20-50 yr periods of less summer storms, the dune ridges stabilized and were not subjected to marine erosion. Such factors account for the preservation of high dune ridges.

Intervals of Surface Stability:
the Soil Chronosequence at Espenberg

Multiple paleosols occur in dune ridges more than 1000 yrs old at Cape Esepnberg. Most of these soils are only weakly developed; for the most part, buried organic (O) or A horizons. These horizons contain dark brown (10 YR 2/2) silt and can be traced laterally for hundreds of meters, in blowout walls. On dune ridges 700-1000 yrs old (the E-5 ridge, see above), organic and silt rich horizons (several cm thick) are found on the surface beneath a continuous crowberry vegetation cover. Following this reference point, I interpret buried organic horizons on older ridges as evidence of a stable vegetation cover with little or no eolian deposition, because of the intolerance of crowberry to sand burial (Mason this volume, Ch. 3). Paleosols on the oldest ridges have undergone spodsolization (B horizon formation).

The co-occurrence of archaeological loci and buried paleosols is particularly clear on several, but not all, Espenberg dune ridges. In Unit I ASTt artifacts are present in a paleosol dated at 3800-3700 BP. In Unit II four Choris and Norton components lie within laterally continuous buried soil horizons, linked by ^{14}C dates to a range between 2700-2500 BP. A Unit III paleosol caps Ipiutak artifacts dated at 1400-1300 BP. Similarly, the earliest Unit IV ridge contains buried Thule remains dated at 700-600 BP, located about 60 cm *below* a surface organic horizon.

In summary, the Espenberg paleosol record reflects a particular combination of climatic and ecological factors. The primary signal is one of stabilized, shrub vegetation and the absence of grasses and appreciable eolian deposition. This situation may indicate increased precipitation which precluded sand transport and was coupled with weaker winds. Stabilized surfaces occur during the intervals of

Units II and IV; implying that short-term fluctuations in wind and storm intensity punctuated these otherwise stormy periods. This interpretation is consistent with the Kobuk River dendrochronological record examined above.

Espenberg Progradation in Relation to Sediment Sources: Offshore Shelf Sands vs. Kitluk Bluff Erosion

The Espenberg spit has evolved under two competing sedimentary regimes: (1) a progradational regime characterized by the addition of low ridges separted by wide swales and (2) an erosional regime during which dunes are built. The two contrasting regimes are evident as differences in the swale widths between beach ridges (Fig. 2.23). I link progradation with less frequent storms and dune building with intensified storminess, for reasons outlined above.

The progradational phase requires a surplus of sediment; either from one of two principal sources: the Kitluk River bluffs or the the southern Chukchi Sea shelf (see above). It may seem paradoxical that progradation occurs during less stormy conditions, if bluff-eroded sand formed a significant part of the prograded sediment. For, bluff erosion should, at first glance, be directly connected with an increase in storm intensity or frequency. To assess this possibility, I must discuss the process of bluff erosion and that of storm induced erosion. The erosion of the Kitluk Bluffs has not been studied fully; so I rely on my own observations and those of my co-worker, J.W. J.W. Jordan (1988, 1990).

The Kitluk Bluffs lie updrift from Espenberg and extend southwest about 20 km to the Kividluk Inlet (Fig. 2.2). The bluffs are 3 to 20 m in height and are composed of silts and sands of middle to late Pleistocene age (Hopkins 1988). J.W. Jordan (1988:341) estimates 0.56 m/yr of recent (1949-1976) bluff erosion. If we simply extrapolate this rate, a total of 2.24 km of erosion may have occurred since 4000 BP. However, this extrapolated rate probably does not accurately reflect long-term erosion. The sediments of the Kitluk bluff are permafrost-bound and contain a well-developed net of ice wedges. Thawing of this ice results in large scale block collapse. Thermokarst collapses extend for several hundred meters along several areas of the coast. The role of the sea as an undercutting agent is unclear; in contrast to the Beaufort Sea coast where high winds and waves often play a substantial role in accelerating the thawing of ice-rich bluffs (Reimnitz and Maurer 1979:338ff). At present, none of the bluffs have thermoerosional niches or have been scarped because of recent storm activity. Quite the reverse is true: seaward of a 2 km long stretch of bluffs, east of the Kitluk River, 2 to 3 m high dunes have built and protect the bluff from erosion. Possibly, the erosion of the bluffs is independent of storm activity. The thawing of permafrost may be a temperature-dependent process. The increased thawing of bluff sediments may be linked with warmer summer temperatures during the progradational phase during 2000-1200 BP as the eroded bluff sediments are incorporated into longshore transport. However, increased vegetation growth may stabilize bluffs during warm periods.

How rapidly does the Espenberg spit prograde in response to bluff erosion? A tentative estimate is possible by examining offshore bar migration rates from the Beaufort Sea (Short 1975:217). Based on aerial photo analyses, offshore bars migrate at an average rate of 70 m/yr, or 1.2 m per day, during the limited open water season on the Beaufort Sea coast, a rate comparable to mid-latitude coasts. If such a rate held on the Kitluk to Espenberg coast, a lag of 35 to 70 yrs would be expected for a bluff eroded mass of sediment--a nearly instaneous tranfer in the geologic record.

The direction and duration of high magnitude storms may minimize the sediment yield following storm-related bluff erosion. A coast-parallel southwesterly wind produces a downwelling velocity gradient, which results in the offshore transport of sediment (Vincent 1986). If high winds and seas form a coastal jet, and are coupled with swell conditions, then large quantities of sand may be transported over several km offshore during a single storm (Niedoroda and Swift 1981). With a succession of many storms during a short time span, eroded sediment sand is removed from removed from the longshore transport system. The result at the spit downdrift is sediment starvation.

Some of this argument might be moot because the limited data from granulometric analyses, described above, indicates that eroded bluff sediments form only minimal contribution of the spit growth. This situation is similar to that of the Atlantic Seaboard where sandy barrier islands are generated from offshore sands, not bluff erosion (Niedoroda et al. 1985:585).

The timing of Kitluk bluff erosion updrift from Espenberg provides a more complex chronological problem. No precise data on Holocene stratigraphic or radiometric data exists for the erosion of the Kitluk bluffs. Intuition suggests that bluff erosion updrift should be a primary factor in Espenberg spit progradation. Differences in orientation between Unit I ridges and all other depositional units (II-IV) in the B complex may be used to infer the extent of erosion in the last 4000 years. Based on these differences, I infer that substantial erosion occurred west of the Espenberg system since the start of Unit I deposition and that the entire Espenberg complex originated farther west than at present. Using photogrammetric estimates of the present amount of erosion (J.W. Jordan 1988:341), the Kitiuk coast, to the west of Espenberg may have been about 2.24 km seaward ca. 4000 BP. From one perspective, the periods of rapid progradation, 4000-3000 and 2000-1200 BP should be directly correlated with substantial bluff erosion. However, this is a period I link to less intense storms and, presumably less bluff erosion. The rate of bluff erosion may not be a critical variable since intense storms would produce a greater movement of sand *offshore* with less directed onshore. Such sands might have remained in storage offshore during stormy periods. Conversely, during calmer periods, net sediment movement was onshore and alongshore since storms had lower intensities and occurred less frequently.

The timing of offshore sediment input is also uncertain. Large scale variations in local alluvial contribution seem unlikely in light of the low sediment yields of Seward Peninsula rivers. Late Holocene variations in the amount of input from the Yukon River could conceivably be significant, as hypothesized by Nelson and Creager (1977). The Wales shoal is actively receiving Yukon sediment but the predominant particle size carried by bottom currents through the Bering Strait is 4ø, coarse silt (McManus and Creager 1963). McManus et al.(1969:1976-77) argue that most of the offshore sand entered the southeast Chukchi Sea at a time of lower sea levels; thus, before 5000 BP. Once the sea levels stabilized, the offshore sands were available for mobilization by the currents onshore and alongshore, with the conditions set to form the Espenberg spit.

Conclusions

About four thousand years ago, sea levels stabilized to near modern levels along the microtidal shores of Kotzebue Sound. At that time, sea level stopped increasing and the large amount of sand on the shelf was able to be entrained by longshore currents and deposited off Cape Espenberg, forming the spit platform and the first beach ridges atop them. To discover the earlier history of Espenberg spit during the early Holocene (10-6 kyr) eustatic sea level rise, an extensive coring program will be required.

The ultimate source of the Espenberg sand is unclear, but may derive either from (1) offshore Chukchi shelf sands or (2) local erosion of sand bluffs near the mouth of the Kitluk River, about 30 km updrift from Cape Espenberg. Quite likely, both offshore and terrestrial sources were involved. The orientation of the earliest Espenberg ridges is northeasterly, at variance from later ridges, which suggests substantial erosion of the adjacent Kitluk coast since 4000 BP, in line with J.W. Jordan's (1988) estimates of recent erosion. The Kitluk River sands are distinctively rich in magnetic ferromagnesian minerals and coarser than the lighter Yukon sands. Ongoing studies of the mineralogy of all three sediments will clarify the role of the particular source(s).

To study the late Holocene evolution of the Espenberg spit, I use several lines of inference, primarily using radiometric dates from archaeological sites as chronological markers. The delineation of chrono- and litho-stratigraphic units relies on the surficial record of geomorphic and ecologic processess, reflected in changes in plant communities, lake development, paleosol formation and the appearance of cryogenic features such as convolute bedding, frost cracks and palsas.

During the last 3500 yrs, the evolution of Espenberg spit has been marked by episodic alternations in the amount of horizontal progradation and vertical dune accretion. Periods of rapid progradation are marked by the addition of berm ridges capped by very low dunes separated by wide swales while the periods of vertical growth show composite dunes, often modified by blowouts, which in section possess a berm ridge nucleus overlain by several generations of dunes, re-activation surfaces and infilling planar bedded sands.

To explain the pattern of alternations, then, I postulate that horizontal progradation occurred during climatic intervals marked by a dominance of low wave energy typical of modern high pressure midsummer conditions, with infrequent storm surges during the summer open water period and lower strength winter wind conditions. Alternatively, dunes were built during climatic periods dominated by higher intensity and frequency storm surges which built higher storm berms. Such higher berms provided higher backbeach deposits subject to winter winds which transferred them into dunes beyond the highwater line.

Progradational regimes correspond to warmer midsummer climatic conditions from 4000-3300 BP and 2000 to 1200 BP. In the former case, paleosols dated to 4000-3750 BP are reported from isolated localities across northern Alaska and northwest Canada: the Ikpikpuk River southeast of Barrow (Rickert and Tedrow 1967), on Banks Island (Pissart et al. 1977), at Cape Denbigh in Norton Sound (Giddings 1964) and in the Nenana River valley south of Fairbanks (Thorson and Hamilton 1977, Powers and Hoffecker 1989). Increased pollen production about 4000 yrs ago is also indicative of increased summer warmth throughout Alaska (Brubaker et al. 1983).

Dunes build, conversely, from 3300-2000 BP and episodically during the last 1000 yrs, during a net erosional regime. Other beach ridge complexes (Cape Krusenstern, Wales, Sisualik) in northwest Alaska also reveal net erosional conditions 3-2 kyrs ago (Mason this volume, ch. 5). Such stormy, erosional regimes on the coasts are linked with a precipitation surplus and, hence, glacial expansions in the Kigluaik Mts. on the south Seward Peninsula (Calkin, 1988, written communication) and across Alaska (Calkin 1988).

The stormier conditions of the third millennium BP at Espenberg appear linked with the Neoglacial event, as defined by world-wide glacial expansions (Porter and Denton 1967, Porter 1986, Röthlisberger 1988). The date of 3000-2000 BP also parallels the 2500-yr cold climatic event in the Camp Century ice core (Dansgaard et al. 1984). The width of Unit II is about 75% less than the younger dune ridges in Unit IV and may provide a relative measure of the storm recurrence intervals in the 3rd millennium BP--larger storms probably occurred in rapid succession, as compared the last 1000 yrs.

The buried soil dated at 2800-2500 BP on the Unit II ridges may be evidence of increased precipitation or of a temporary pause in climatic cooling. Quite significantly, the record of Espenberg paleosols correlates well with Sorenson and Knox's (1974) reconstruction for late Holocene displacements of the forest/tundra boundary in north central Canda, which shows northern advances of treeline (and paleosols) at ca. 3500 and 1600-1100 BP, with a slight advance at 2600-2200 BP and a southward retreat at 2900, 1800 and 800 BP.

The period between 2000 and 1200 yrs BP contains almost half of the progradation at Espenberg and correlates with a similar progradational regime on the Shishmaref barrier islands during 1500-1000 yrs ago (J.W. Jordan 1989,1990, Mason this volume, ch. 5). Peat formation atop alluvial terraces is widespread 2000-1000 BP in north central Alaska (Hamilton 1981) and Seward Peninsula (Kaufman et al. 1989). As mentioned above, this period experienced fewer, less intense storm surges (2 per century) and lessened winter winds. The most recent ridges formed in the last 1200 yrs (Unit IV) have an elevated dunal topography, only partly reflecting their younger age.

The granulometric data support the interpretation that the Unit IV ridges are unique and represent conditions differing from earlier times (ie.,Units I to III). Thus, to qualify the chronologic/climatic interpretation offered above: the heightened *wind* (not storm) intensity events occuring before 1200 BP, ie. the onset of Unit IV, might have been less intense than the events reflected in Unit IV times. Hence, the small dune ridges of 3.5 kyr , 3-2 kyr, ca. 1.8 kyr and ca. 1.4 kyr record wind intenity events of less severity, or subsequent erosion by storms, in the case of the 3-2 kyr ridges.

Alternations in horizontal progradation and vertical dune growth may be better explained by referring to the cumulative dune/beach sediment budget, a concept advanced by Psuty (1988) and described above (Fig. 2.11). As I infer at Cape Espenberg, vertical dune growth is greatest in areas experiencing net beach erosion while net depositional, ie. horizontally prograding, beach settings reveal a series of low dunes separated by wide swales. Thus, the history of Espenberg reveals a net erosional system in the last 1200 yrs, correlated with vertical dune growth, compared to a net progradational system in the preceding millenium between 2000-1200 BP.

Finally, by comparing the Cape Espenberg sequence with East Asian and Alaska proxy climatic records, I hypothesis that a parallel climatic regime is affecting sedimentary deposits in both regions. Briefly, cooler climatic conditions produce dust storms and anamolous winter thunderstorms in China, while Espenberg witnessed dune building--not unlike similar occurrences along the margins of the North Sea. Some of the cross-correlations may be speculative, further research should be able to establish more precise linkages.

Chapter 3

The Geomorphic Evolution of Coastal Dunes and Blowouts in Northwest Alaska: Taphonomic Implications for Archaeological Sites

Introduction

Though Alaska is not renowned for vast expanses of sand, relict dune fields and coastal dunes form a substantial part of its surficial cover. Dune landscapes are an inheritance from the arid, windy conditions of the late Pleistocene (Hopkins 1982, Lea 1989). Inactive, vegetated dune fields cover thousands of square kilometers of the Tanana valley (Collins 1985) and the Arctic coastal plain (Carter 1981), for example, while smaller active dune fields are found in the Kobuk River valley and elsewhere (Fernald 1964, 1965). Coastal dunes occur widely along the shores of north and west Alaska (Black 1951). Though eolian deposits have been mapped at a reconnaissance level, little research pertains to their history and development.

Alaskan archaeologists tend to ignore eolian deposits both in survey strategy and in site interpretation. Dune fields in the High Plains of Wyoming have yielded numerous bison kill sites (Frison 1978), while in Alaska D.S. Stanford conducted the *first* archaeological survey of the Kobuk Dune field in 1989 (Stanford et al. in press). On the Alaskan coast, several early sites were found in dune blowouts: for example, the Koggiung site, on the Alaska Peninsula (Dumond 1981:86), and the Anangula blade site, in the Aleutian Islands (Laughlin and Marsh 1954:28-29, Aigner 1978). A chronology of blowout erosion could provide important paleoenvironmental information in areas such as the presently humid climate of the Aleutians.

The coastal dunes of northwest Alaska were not considered a promising locale for archaeological sites by J. Louis Giddings (1964:251,255). However, a 1986 National Park Service survey of the Seward Peninsula coast, under the direction of Schaaf (1988a) reported nearly 150 archaeological loci; nearly all within eolian deposits and many substantially older than the late prehistoric period.

The transitory nature of dunes dissuades many researchers from serious study of sites within dunes, but the negative aspects of possibly ambiguous stratigraphy may be balanced by the advantages of rapid burial and good preservation. Since site visibility depends largely upon disruptions in the vegetation cover, a taphonomic approach to dune processes is necessary. In this review, I provide contextual data on the depositional environments of an Arctic dune field, emphasizing the role of the biota. The development of dunes and deflation basins (blowouts) reflects interrelationships between plant cover, precipitation balance, water table and wind regime. Two years of surface level measurements (1987-1989) allow the quantification of these geomorphic and biotic processes.

Description of the Study Area: Cape Espenberg

Cape Espenberg is a large complex spit at the north tip of Seward Peninsula, located on the Arctic circle (66° 33' N., 163° 30' W.) (Fig. 2.2). Lying on the shores of the Chukchi Sea, at the southern entrance to Kotzebue Sound, the Espenberg spit has prograded over 2 km in the last 4000 yrs (Mason this volume, Ch. 2). Though ultimately marine in origin, the over 15 shore-parallel beach ridges are covered by dunes of variable height, ranging from <1 m to >20 m. Higher dune ridges occur in discrete areas; most are closest the modern shore. I establish a chronology for the history of the

Espenberg spit by using minimum age estimates from ^{14}C assays from archaeological sites atop the ridges (Table II-g, Mason this volume, Ch. 2).

Meteorology and Wind Climate

Northern Seward Peninsula lies within a transitional zone between a polar climate (mean monthly air temperature less than 10°C) to the north and the polar oceanic climate (fairly high annual precipitation) to the south (Pease 1987). Consequently, the Seward Peninsula coast has a moderate maritime summer climate, but winters are cold and windy. The Chukchi Sea is bound by fast ice from November to early June. Limited climatic data from Shishmaref (about 100 km southwest of Espenberg) show that mean maximum July temperatures vary over only a narrow range, between 5.8°-12.2° C while February mean minimum temperatures fall between -24° and -16° C. Record extremes are -44.4° C (February 1947) and 25.5° C (July 1946). Precipitation is low, typically less than 20.5 cm per year (Leslie 1986). A perennial snow cover persists on land from October to May and landfast pack ice forms offshore during the same period. Evaporation is generally low, due to low air temperatures, which allows the long term persistence of water on the landscape, despite low precipitation levels. Interannual climatic variability can be very drastic; in winter 1989, for example, February precipitation was over 3 to 4 times mean levels, while the summer of 1988 recorded conditions 5 to 20% drier (WMO 1988, 1989).

Winds affect the Seward Peninsula coast in association with the passage of storms from the North Pacific through Bering Strait. Wind rose diagrams from Tin City (La Belle et al. 1983), about 150 km to the southwest, indicate nearly a uni-directional distribution of winter winds; with north, northwest or northeast winds. Southerly winds are significant only in summer months, though, even then northerly winds remain a significant component of winds affecting the coast.[1] The calmest, least windy periods are during mid-summer, June and July; erosion is least likely during this time which is often dominated by stable high pressure systems.

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[1] The closer weather station at Kotzebue, about 40 km northeast, is more sheltered by low hills than Espenberg but on occasion, south or east winds may be more accurately reflected at Kotzebue than at the more distant Tin City station near Bering Strait.

Landscape and Vegetation

Cape Espenberg is more than 100 km beyond tree-line, within the region of continuous permafrost; factors which exert a profound influence on geomorphic and biologic processes. The permafrost level is approximately parallel to the topography, but extends deeper under the ridges and is shallower under the swales. The low relief of the ground water retards ground water flow and allows many lakes, ponds and small pools to form (Hopkins 1986, field notes). Many cryogenic features occur on the Espenberg spit, including surface features such as string bogs, palsas (ice-rich peat mounds), intersecting networks of frost cracks and subsurface features such as soil involutions and deformed beds.

Two topographically different types of sand ridges form on the Cape Espenberg spit; each is related to different depositional processes. Elevated dune ridges build closest to the modern beach and in certain areas toward the interior of the complex, while flat ridges, lacking dune ornamentation are located more than 500 m from the beach. The most seaward dune ridges are bell-shaped in cross section and are covered with lyme grass *(Elymus arenarius mollis);* they attain heights of up to 20 m above mean sea level (MSL).[2] Stabilized ridge surfaces with no exposed, erodible sand have a vegetation cover of crowberry *(Empetrum nigrum)*, bearberry *(Arctostaphylos alpina)*, low bush cranberry *(Vaccinium vitis idaea)* and other prostrate shrubs. Plant species diversity increases with distance from the beach zone, as marine spray decreases and standing fresh water increases.[3]

Inter-ridge swales, with permafrost at shallow depth, vary considerably in width (up to 200 m) across the Espenberg spit. Ice-cored mounds (palsas) and lakes form in the swales, with sedges (*Carex aquatilis*), labrador tea (*Ledum palustre*) , blueberries (*Vaccinium uliginosum*), spaghum and other mesic shrubs common. Ponds and lakes up to 2 km in length form at Espenberg within swales; Racine (1974:8) estimates that they cover about 14% of the land of Cape Espenberg. Though resulting from a

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[2] For this study, Mean Sea Level (MSL) refers to mean low water because tidal fluctuations are so insignficant. Field observations were made during summers of 1986-88. No gauge data is available for this region.

[3] Botantical collection and descriptions by Jeanne Schaaf (1986, written communication), identification by Marilyn Barker, Univ. of Alaska, Anchorage.

precipitation surplus, the lakes probably form by the degradation of peat, which produces a distinctive iron-stained algal or baterial muck on the lake floors.

Eolian Sediments

Granulometric analyses (Fig. 2.17) of 105 samples from Espenberg dune/beach ridges reveals that the particles are fine sand (x= 2.33ø±0.19). No statistically significant differences are observed between dune sand and modern beach sand. In fact, the modern beach may be largely composed of material eroded from dune ridges and later re-deposited a short distance (50-150 m) downdrift. Differences in the mean grain size are noted between the coarse sand in the most recently deposited ridges, less than 1000 yrs old, which is coarser than that in any of the earlier ridges, which are finer grained. The difference relates, presumably, to a shift in the sediment source, the intensity of winds during colder climatic intervals or a combination of the two factors.

Dune Formation at Cape Espenberg

The formation of dunes at Espenberg follows the development of beach ridges, as is demonstrated by the stratigraphic relationship revealed in cutbank exposures at the east end of Cape Espenberg. At the base of Espenberg dune sections, the marine facies (as defined by Roep 1986) consists of steep cross beds inclined (up to 30°) landward and capped by a horizontal bed rich in shell debris (Mason this volume, Ch. 2). Incipient dunes grow at the rear of the modern beach, beyond the limit of the highest storm waves, anchored by grass which is nourished by higher nutrients imparted by drift detritus (Ranwell 1972). The long-term persistence of dunes depends on the ability of the grass to anchor sand and outpace storm erosion (Olson 1958a, Ranwell 1972:148, Hesp 1984).

Dune construction requires several preconditions (Pye 1983a): (a) a supply of sand on the backbeach, (b) high winds capable of moving the sand, and (c) moisture conditions that allow sand movement (Greeley and Iversen 1985:85-86). The presence of sand capturing plants helps the process, they are not indispensable (Cooper 1958:66). Dune-building is likely a multi-seasonal process at Espenberg. The first two pre-conditions are satisfied best when stormy weather is prevalent, in recent decades, from late July through September (Wise et al. 1981). Sand is moved onto the back beach during the waning phases of autumn storm surges (cf. Short and Hesp 1982, Ritchie and Penland 1988). Sand movement leading to accumulation in the backbeach may occur in late winter/ spring (April through June, in this Arctic setting), as in Ireland (Carter 1986). The beach area is often dry and free of snow during April and May and observers report sand transport (J.W. Jordan, 1988, field notes). When I visited the region in mid-June, just after shorefast ice breakup, I observed low (<50 cm high) unvegetated barchan dunes on the mid-beach (Fig. 3.3), which were likely the product of winter and spring eolian processes because no marine incursions had yet occurred.

To a large measure, the topography of the Cape Espenberg spit is governed by plant ecology. First of all, plants further sand deposition by introducing surface roughness and thus changing the flow and transport competence of the air (Olson 1958a). Dunes also build due to the high tolerance of lyme grass for burial by sand (30-60 cm per annum), its ability to root deeply (several meters) and to expand laterally (up to 1.5 m) by rhizomes (Chapman 1978, Ranwell 1972). In fact, "continued elongation [of the grass stem]...depend[s] on the continued deposition of sand" (Bond 1952:221). Beach grass is tolerant of higher concentrations of salt (up to 12%) than most other grasses, but can be subject to wind damage (Bond 1952:219).

The vertical accretion resulting from the presence of lyme grass is complemented by the horizontal web of the root systems of prostrate shrubs such as crowberry and willow (*Salix* spp.). Crowberry and willow provide a stabilizing influence and outcompete rye grass as dune ridges accrete farther landward, isolated from the active sand source on the beach. While beach rye tolerates and may even require salinity, many other plants cannot. Biotic assemblages of sedges (*Carex* spp.), sphagnum mosses and tussock sedges predominate in wet inter-ridge areas. The contrasts between the different plant communities are readily observable on aerial photos and provide a means to delineate depositional units (Mason this volume, Ch. 2).

If a new foredune grows seaward, this cuts off sand supply to any older dunes, leading to a decline in grass flowering and growth; and, consequently, curtails the vertical accretion of the dune (Olson 1958a, 1958b). Vertical accretion of dunes is limited by the stabilizing influences of roots systems and is maintained in equlibrium with the wind climate. Observations from the English coast reveal that the greatest sand accretion occurs up to 50-60 m windward of the crest in active dunes, but only 6 m windward in less active ones (Ranwell 1958:92). Erosion, conversely, is most active on the leeward aspect. I observed substantial deposition, up to 70 cm, on the crests of Espenberg dunes, windward from marine cut scarps (Mason 1988, field notes).

British researchers estimate that a 15-30 m high dune ridge builds in about 50-100 yrs, a yearly rate of 30 cm; depending on the balance between waves, tides and foredune establishment (Ranwell 1958:99). Similar rates of dune growth are also reported along the Atlantic shores of North America (Goldsmith 1985:345ff). However, dune accretion may be slower on the Arctic coast at Cape Espenberg; I estimate dune growth rates at about 100-300 yrs per ridge, based on archaeological bracketing ages of 300-200 BP on the second ridge landward and dates of about 600-500 BP on the third ridge (Mason this volume, Ch. 2). The formation of swales, the absence of dunes, requires a combination of decreased sand supply and, possibly, wind scour behind an actively forming dune, as suggested by Bird and Jones (1988: Fig. 7).

The height of dunes differs from place to place along the Espenberg spit. The highest dunes lie in the western part near the mainland and are up to 20 m above MSL, while dunes decrease in elevation to the east toward the Cape (Mason this volume, Ch. 2). This pattern reflects the direction of longshore transport and the leading edge of storm impact along the coast (Cleary and Hosier 1979, Davis 1985, Leatherman and Zaremba 1987). The pace of dune-building atop ridges relates to the interaction in sediment balance between the beach and dune areas. As Psuty (1988: 3) remarks:

> ....large pulses of sediment separated by long intervals may give rise to formation of substantial dune ridges whereas smaller more frequent pulses of surplus sediment would give rise to the smaller dimensional beach-ridge topography.

At Espenberg, the construction of dune building occurred within discrete temporal intervals associated with variations in storm and wind intensity which at times produced a surplus of sand on the back beach (Mason this volume, Ch. 2). Espenberg dune ridges are separated by swales of varying width, ranging from less than 20 m to over 200 m (Fig. 2.23, Mason this volume, Ch. 2). According to Tanner (1988:86) such patterning in ridge spacing reflects the time-lag between storms violent enough to build beach ridges. Espenberg swale width data indicate that storm frequency varied during different depositional sequences of ridges. Storminess increased 3300-2000 BP and 1200 BP to the present, relative to the time before 1200 BP (Mason this volume, Ch. 2).

After the stabilization of the dune surface, several post-depositional processes assume importance, notably pedogenesis under stable conditions and blowout formation under erosive conditions.

Soil Development

Soil profile development in sand dunes or anywhere else requires a stable vegetation cover (Thompson and Bowman 1984, Thompson 1981). Rates of soil formation are determined by the amount of water entering the dune and the balance between erosion and sedimentation (Thompson and Bowman 1984:277). A thick surficial organic (O) horizon, ie. an epipedon (Soil Survey 1975), forms in areas not subject to active eolian deflation. At Espenberg, stable areas are often covered by crowberry and other low scrubs (willow, blueberry, etc.) with horizontal root systems. Twice as much organic matter may be accumulating in swale environments than on dunes, with optimal conditions during high precipitation intervals (Ranwell 1959). In areas subject to seasonal ponding and desiccation, humate compounds and iron minerals in the sand are oxidized, resulting in mottling and coating of individual grains (Bigarrella 1975:119). Episodic ground water percolation results in the downward displacement of heavier grains and produces distinctive tongue-like features at Espenberg (Fig. 2.25). These pedogenic processes produce spodosols, a subsurface B horizon (Soil Survey 1975). Spodsolization may be counteracted by water table fluctuations high in base-rich compounds, especially in the inter-dune environment (Ranwell 1959:586).

On older ridges at Espenberg, iron oxide horizons become indurate and form platy "petroferric" layers. The reddened sand horizons at Espenberg are probably cemented by authigenic goethite (aFeO·OH), forming under oxidizing conditions (Pye 1983b:209). Reddening due to hematite (Fe_2O_3) requires the seasonal occurrence of high temperatures and low interstitial water; circumstances not prevailing at present (Pye 1983b:209). Analysis is ongoing to distinguish the mineralogy of reddened sands at Espenberg.

In Espenberg paleosols dated 3800-3500 BP (Mason this volume, Ch. 2), there are evidences of infiltration structures; "discontinuous, wavy bands which result from the concentration of vertically infiltrated fine material" (Pye 1983b:207). These silt-rich beds are associated with down-profile migration of fines, deposited due to changes in the wetting or freezing front.

In areas with extensive eolian activity, or on younger ridges, paleosols are less developed, consisting of thin silt laminae. These accumulations of finer sediments are eluviated from the surface and are deposited at subsurface moisture and pore space thresholds (Soil Survey 1975).

Erosional Processes Modifying Dunes and Promoting Blowout Formation

Blowout formation on dunes is related to two geomorphic processes: (1) accelerated erosion near upper slopes as winds intensify near dune summits (Bagnold 1954, Olson 1958a, Gares and Nordstrom 1987, Jungerius and van der Meulen 1988) and (2) climatological factors such as high solar insolation on southern slopes which produce an incomplete vegetation cover (Jungerius and van der Meulen 1988). As long as plants protect the sand ridge surface from wind attack, the development of blowouts is more or less prohibited (Cooper 1958:73). In addition to binding sand, plants act to decrease wind velocity above the surface (Ranwell 1972). The death of even individual plants lessens this protection. A dominance by a single plant species on portions of older ridges may lead to the depletion of nutrients and the death of many individual plants which could produce a significant gap in the vegetation cover. Wind scour around the stems of dead or marginally surviving plants also furthers the formation of small deflated areas: incipient blowouts (Jungerius et al. 1981:376, Rudberg 1966).

Crowberry (*Empetrum nigrum*), a slowly-growing prostrate shrub usually no more than 5 cm above the surface, form a mono-species stands over 100-200 m^2 areas on Espenberg ridges. Disruptions in crowberry cover may lead to blowout formation. Individual shrubs form clones and grow radially, eventually forming interconnected carpets up to hundreds of meters in extent. The roots, often 1 cm thick, are especially linear and provide a stablizing network. Crowberry favors well-drained areas and is intolerant of water-logged conditions, animal grazing and sand burial; due to its height of generally 50 cm or less (Bell and Tallis 1973).

On the youngest ridges, disruptions in the vegetation cover, or truncation of the ridge itself, may arise after storm waves overwash, undercut or even breakthrough dune ridges (cf. Cleary and Hosier 1979, Leatherman and Zaremba 1987). Evidence of marine erosion is particularly compelling in several locations along the Cape Espenberg complex (Fig. 3.1). On aerial photos the transgressive nature of marine overwash is very clear, especially in the western and central portions of the Espenberg complex, immediately adjacent to former or active surge channels (Fig 3.1). On the ground, a pronounced scarp may be evident on the seaward face of the ridge, reflecting this marine undercutting. As storms undercut or breakthrough the ridge, the resulting discontinuity leads to the activation of sand and the translation of the ridge landward, in a manner described by Bagnold (1954:206ff). The process is similar to blowout development sequences described on Scottish coastal dunes by Ritchie (1972:31) who noted five types based on "the essential process of undercutting, slumping and local lee-side redeposition." Two of Ritchie's blowout types develop from the beach through the dunes, forming corridors or V-shaped re-entrants.

Trampling also disturbs groundcover. Recreational management studies document that even very infrequent walking over several weeks can lead to significant disruption of coastal dunes along the Atlantic seaboard (Goldsmith 1985:320). The traffic of large ungulates such as caribou/reindeer or moose may also lead to the destruction of vegetation (Seppälä 1984). Although indigenous caribou populations on Seward Peninsula declined by the late 1800's, introduced reindeer herds remained sizable until 10-15 years ago. As late as the early 1970's, Fred Goodhope, Sr. of Shishmaref managed a reindeer herd of nearly 3,000 animals (Stern et al. 1980:89, D.M. Hopkins, 1990, personal communication) and maintained a corral on the western part of the Espenberg spit complex. Doubtless many of these animals found their way onto dune ridges--as evident from the occasional reindeer bones found on the surface.

Burrowing activities of smaller mammals such as arctic foxes and ground squirrels are also particularly effective in disturbing vegetation cover. Foxes occasionally dig in archaeological sites to scavenge bones from middens or graves. Fox burrows are particularly common at Espenberg and contribute to blowout evolution. My own informal observations indicate that fox dens are found at least every 0.5 km laterally across some dune ridges (Mason 1987, field notes).

Fires may also destroy vegetation and lead to the formation of blowouts, as documented in Quebec (Filion 1983). Though fires are fairly common in the nearby inland Noatak valley tundra--79 in a 28 yr period (Racine et al. 1985), the occurrence of fires along the more mesic coast is unstudied, but is probably infrequent. Some idea of the colonization rate for bare sand areas was obtained by examining the re-vegetation

Fig. 3.1. Oblique Photograph of Cape Espenberg B complex. Storm surge scarping of dunes is followed by blowout erosion.

of a drilling pad from which the vegetation cover was removed, 3 km west of the Espenberg River (Racine 1977:16ff). Only three species were found in 1976, two growing seasons after the disturbance: sedge, lyme grass and beach daisy (*Chrysanthemum bipannutum*). Sand had moved over 30 m to the south of the margin of the drilling pad, with little sand drifted to the north. Sand newly deposited on the leeward edge of the pad resulted in a "distinct raised ridge" (Racine 1977:17) that interrupted drainage in places.

Blowout Evolution at Espenberg: a Typology

Hesp (1988) proposes a "morpho-ecologic" typology for Australian coastal foredune evolution. Hesp's five stages of foredune morphology reflect a general decrease in vegetational cover and an increase in the deepening and merging of erosional troughs within a dune. Completely modified foredunes, Hesp's stages 4 and 5, are little more than residual knobs of the original dune. Espenberg dune ridge evolution broadly resembles the sequence described by Hesp, but shows some peculiarities. By contrast, the types of Ritchie (1972) are more metaphoric (eg. "cigar-shaped," "cauldron and corridor," "scooped hollow").

Blowout development on the prograding Espenberg spit also follows a predictable pattern, showing an increasing complex topography with time and distance from the beach (Fig. 3.2). The evolution of blowouts depends on plant community composition on individual ridges and the disruption of vegetation cover, which allows the re-mobilization of sand. On well-drained ridges more than 100 m from the beach, crowberry often totally covers the surface. As noted above, the crowberry cover is especially vulnerable to disruption and initiation of blowouts. However, blowout formation occurs even on the youngest predominantly grass-covered ridges nearest the beach. The approximate temporal relations of dune ridges are inferred from limiting dates obtained by radiocarbon assays on archaeological and geological samples (see above and Mason this volume, Ch. 2). Thus, I arrange blowout types into the following time and distance-related series.

Fig. 3.2. Aerial Photograph showing the stages of blowout formation evident on Cape Espenberg: Stage A–isolated blowouts; Stage B–additions to original blowout; Stage C–repeated cycles of blowout formation; Stage D–healed blowouts.

Stage A

Blowouts form on the dune ridges adjacent the beach, but are isolated features, occurring independently of one another, usually about 50-100 m apart laterally (Figs. 3.2, 3.3). In its initial stage, the blowout often lies on the windward aspect of the dune and is oval in shape, oriented parallel to prevailing wind direction. Erosional cuts reveal primary dune bedding with no evidence of multiple cycles of blowout cut and fill. Lyme grass (*Elymus arenarius mollis*) commonly comprises 90-100% of the cover[3] on the youngest ridges, but stems of sage (*Artemisia tilesii*) colonize the drier, leeward aspects. Sand supply is often abundant on the most seaward ridges and a few overbluff, unvegetated dunes form atop the ridges. Storm erosion may cut scarps in dune ridges and provide an avenue for further wind induced erosion.

Stage B

Dunes farther removed from the active beach are cut off from beach sand sources; as a result, the flora shifts to a crowberry-low bush cranberry dominated community, with cinquefoil (*Potentilla villosa*) and lyme grass in disturbed zones. Blowouts increase in abundance on successively more landward ridges (Fig. 3.4). Younger blowouts develop along the margins of older ones. Ultimately, a series of closely related, nested blowouts results, resembling cellular additions to the original blowout.

Stage C

With continued erosion, only residual knobs remain within a zone of generalized deflation. Erosional knobs bear scarped sides on one or more faces and may rise several meters above deflation basins. As many blowout basins coalesce the resulting pattern grows more hummocky (Fig. 3.5). Plant community composition often reveals the state of blowout evolution; actively accreting knobs maintain a monospecific lyme grass cover and stabilized surfaces are covered with crowberry. If

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[3]Botantical collection and descriptions by Jeanne Schaaf (1986, written communication), identification by Marilyn Barker, Univ. of Alaska, Anchorage.

Fig. 3.3. Blowout Evolution–Stage A. Formed on the youngest ridge, E-1, at Cape Espenberg, less than 200 years old. Stage A blowouts are first generation features, forming as the vegetation cover is disrupted.

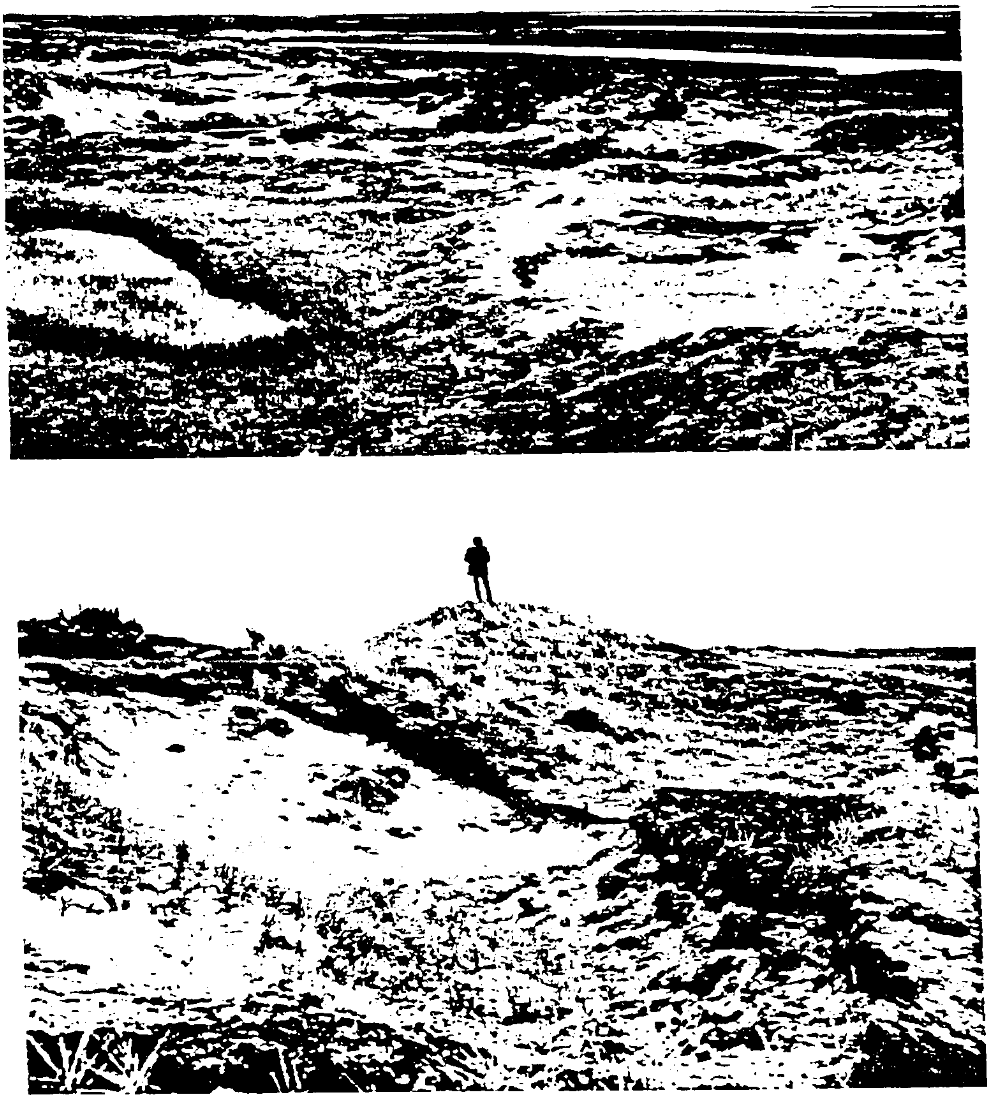

Fig. 3.4. Blowout Evolution–Stage B. Additional blowouts form at the margins of Stage A blowouts, resulting in a cellular appearance in plan view. Note the wall collapse of vegetation bound blocks as the wall is undercut.

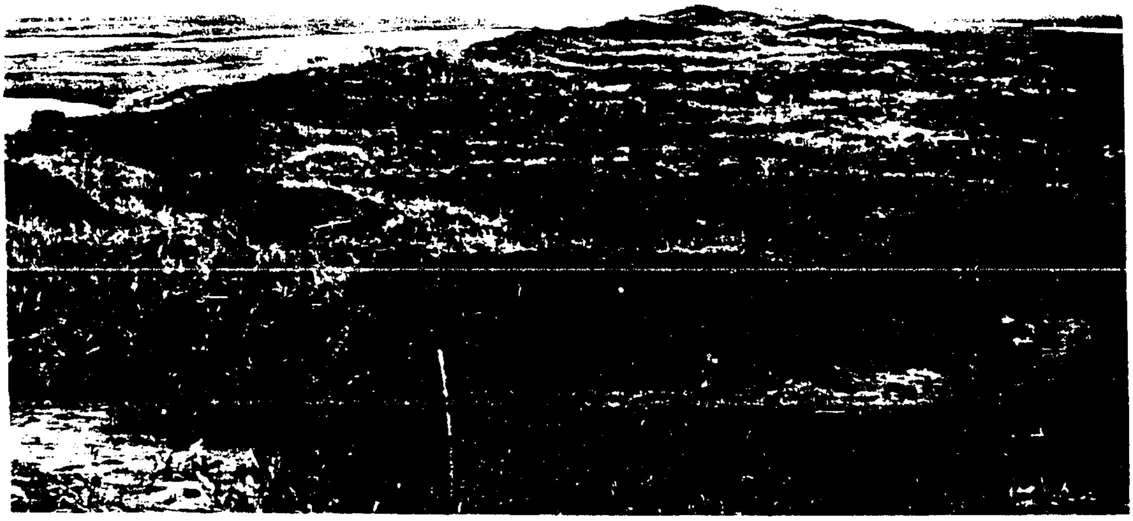

Fig. 3.5. Blowout Evolution–Stage C on the E-14 ridge, 3300-2000 years old. A hummocky topography results after several cycles of blowout formation. Former surfaces are evident in sidewalls as buried organic rich horizons.

the dune ridge remains above water table and a new cycle of erosion is initiated, a complex topography of blowouts at varying stages of evolution may develop. In some portions of the Espenberg spit, it is possible to estimate long-term average rates of accretion or erosion based on the occurrence of archaeological sites within blowouts, as described below.

Stage D

Re-vegetation of blowout basins provides a stabilized surface and no further blowout development occurs. Many ridges in the lower portions of the spit contain a topography marked by shallow basins, the stabilized surfaces of former blowouts. The nearness of water table in middle regions of the spit probably hinders the continued erosion of blowouts in this area. Plant cover within inactive blowouts is continuous and includes mesic species such as blueberry, dwarf birch and willow.

Estimating Deflation Rates at Espenberg

Methodology

To study blowout evolution, a stratified, non-random sample of twenty four blowouts and one incipient dune area (Fig. 3.6) was selected for study using the following variables: (1) orientation; (2) size; (3) depth; (4) vegetation cover; (5) presence or absence of seasonally standing water; (6) elevation above water table; (7) distance from modern beach; (8) presence or absence of paleosols; (9) proximity to residual dune massses; and (10) presence or absence of archaeological sites.

Each blowout was mapped using a Silva compass and 50 m tape. Observations included: active eroding aspects, type of vegetation cover and photo-documentation. Blowout orientation was determined by observing eroding scarps (Rudberg 1966), the longitudinal axis and ripple patterns on the basin floor.

The principal objective of blowout monitoring was to document the amount of sand moved during the study period, August 1987 to July 1989. To achieve this goal, I implanted calibrated stakes within the blowout hollows as a baseline for subsequent re-visits. Modifying the procedures of Seppälä (1984), wooden survey

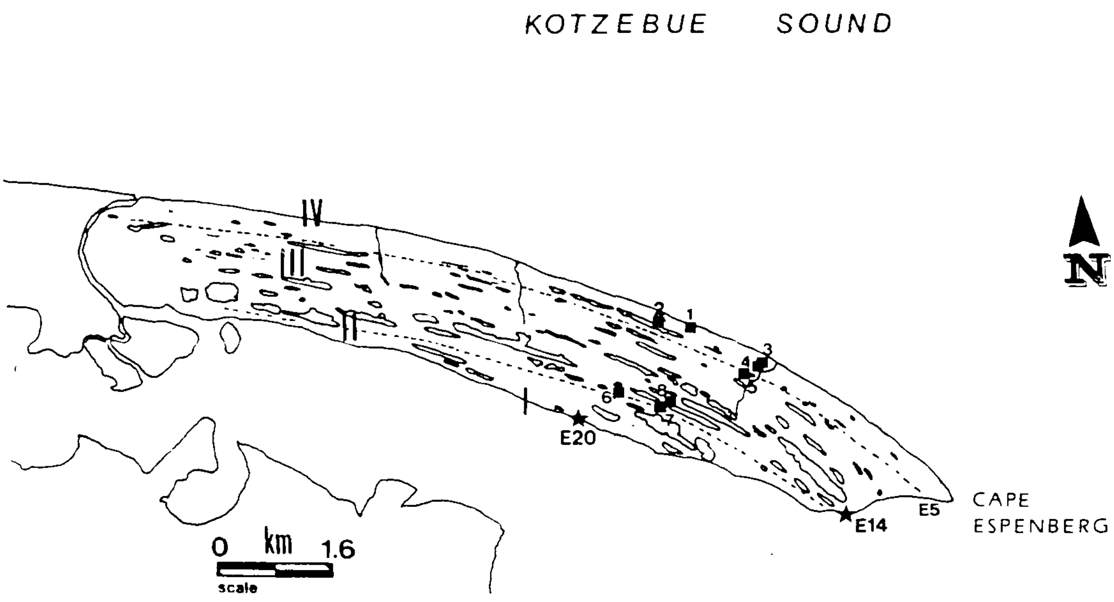

Fig. 3.6. Map of Blowout study locales at Cape Espenberg. Locales 1 to 4 lie within Unit IV, dated to 1200 BP to the present. Locales 5 and 8 are within Unit III, 2000-1200 years old. Locales 6 and 7 are on Unit II, about 3000-2000 years old.

stakes, 0.5 cm thick, 35 cm long, were used. Tipped with phosphorescent orange paint, these thin stakes were aligned parallel with the dominant wind direction to minimize aerodynamic effects (some minor, <2 cm deep, cratering was observed near some stakes).

Size and Shape of the Blowout Study Population

The sample of twenty-four blowouts derives from six different dune ridges at various distances up to 1.8 km from the modern shore, which contained the incipient dune study area. Ridges are designated by arabic numerals increasing in the landward direction (ie. Espenberg, E, 1,2,3...). The blowout sample is divisible into eight discrete study locales (Fig. 3.6). To gauge deflation rates, I selected blowouts from several different temporal periods (Mason this volume, Ch. 2). Ten blowouts are atop ridges E-1, 3 and 5; high ridges less than 1200 yrs old. Two study areas, with six blowouts, lie on ridges E-6 and E-12 which are between 2000-1200 yrs old. Two study areas, together containing 8 blowouts, are located on E-14 ridge, which age estimates place between 3000 and 2000 yrs old.

The sample distributed within the eight study locales include a range of blowout types, varying in size, shape and orientation. Stage A and B blowouts formed most of the study population because these are still actively growing. Using scarp aspects, blowout orientation shows a tight clustering within the northwest (n=10, 42%) or southeast (n=10, 42%) quadrants. A cautionary note should be added since many of the southeast oriented blowouts lay on low ridges and were less than 50 cm deep, with amorphous boundaries, and hence, difficult to determine orientation.

Only three of the studied blowouts are over 1000 m^2 in area, and the remainder show a wide dispersion in size (Fig. 3.7). The range of blowout area lies between a minimum of 0.81 m^2 to a maximum of 1856 $m.^2$ Median size is 42.5 m^2 and average size is 233 $m.^2$ The blowouts cluster in several size ranges: (a) 2-5 m^2, (b) 810-20 m^2 and (c) 40-70 $m.^2$ The largest blowouts occur either on the young E-1 dune ridge and the wide 2000-3000-yr old E-14 ridge. Blowout depths also depend on the height of the dune and are limited by depth to water table, about 4 m from basin to highest prominence.

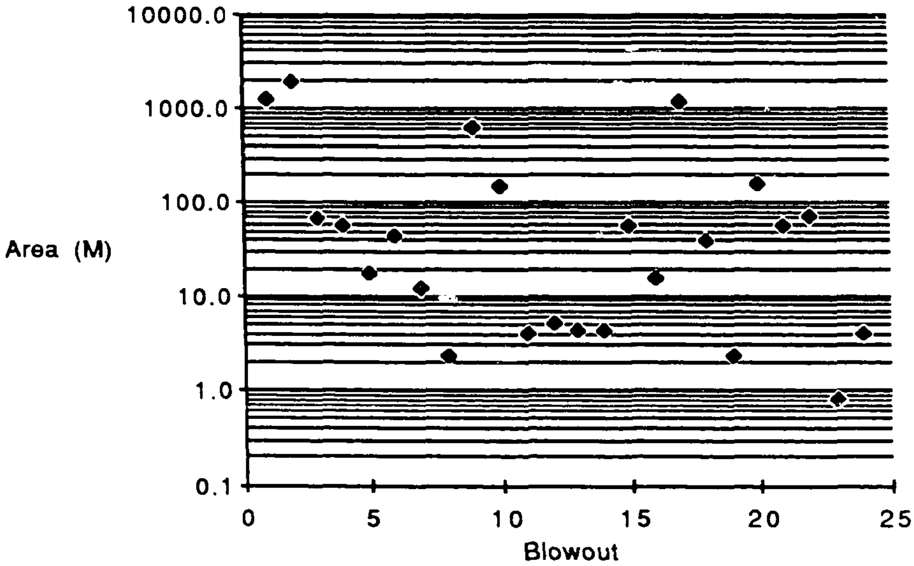

Fig. 3.7. Graph of Size Range of Blowout Study Population at Cape Espenberg. Blowouts range from < 1 m in area to over 1500 m.^{2} The largest blowouts occur on either the most landward or the oldest high dune ridges. Blowouts 1 to 10 lie in Unit IV, Blowouts 17 to 24 lie in Unit II.

Vertical Changes from 1987 to 1989

Changes in vertical elevation were observed in 20 of the 24 blowouts (83%) during the year 1987-1988 (Figs. 3.8a-3.8d). A different pattern was apparent in 1988-1989: only half the 24 blowouts recorded changes (Figs. 3.8a-8d). The dominant geomorphic process in blowout basins involved deflation, not accretion. The amount of deflation was surprisingly high for a single year in some of the blowouts. In 1987-1988 the greatest amount of deflation (-10.0 cm) occurred on the youngest (E-1) ridge; expectably, the greatest amount of deposition (+13.0 cm) was observed on the foredunes (Fig. 3.8a). In 1988-1989 the same trend held up, with 8.5 cm of deposition on the incipient dunes and 10.0 cm of deflation in blowouts on the youngest elevated dune ridge (Fig. 3.8a). However, one of the incipient dunes in the back beach was completely eroded, presumably by the intense storms of August 1988 (Mason 1988, field notes).

Though elevation changes were observed in more than half the blowouts, most changes were minimal, amounting to 2.0 cm or less (Fig. 3.8a-8d). Many of the vertical changes were sporadic; although erosion occurred in 1987-88, deposition might predominate at the same location in 1988-89. An example is shown in Fig. 3.8d which shows the 14th ridge blowouts.

Vertical changes were most notable on the dunes nearest the sea and, to a lesser extent, on dune ridges elevated at least 2 m above the water table. Thus, the amount of change seems related to the height of the ridge above the water table and above sea level. Significant erosion occurred on ridges higher than 4 m MSL: ridges E-1, 5 and 14 (Figs. 3.8a,3.8b and 3.8d). Erosion was less pronounced, in most cases very minimal (Figs. 3.8b,3.8c), on ridges E-3, 6 and 12, which are comparatively lower (only 2-4 m above MSL) in elevation. Predictably, little erosion occurred in blowouts containing seasonally ponded water--a trend clearly seen in July 1989 when standing water was still present in several blowout basins (on ridges E-14 and E-1a). Low evaporation rates and the presence of seasonally frozen ground in blowout basins contribute to a perched water table, allowing the persistence of water into July (no appreciable rain fell in the two weeks prior to my visit).

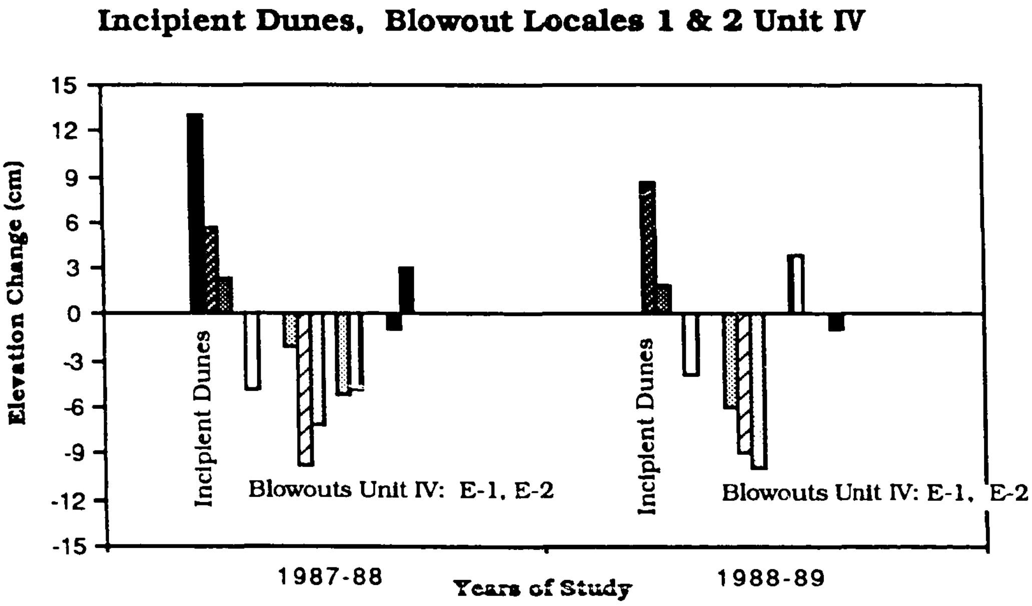

Fig. 3.8 (a) Elevation changes in Espenberg blowouts, 1987-1989. Incipient dunes and Unit IV ridges E-1 and E-2. Measurements are from survey stakes emplanted in blowout basins in summer 1987.

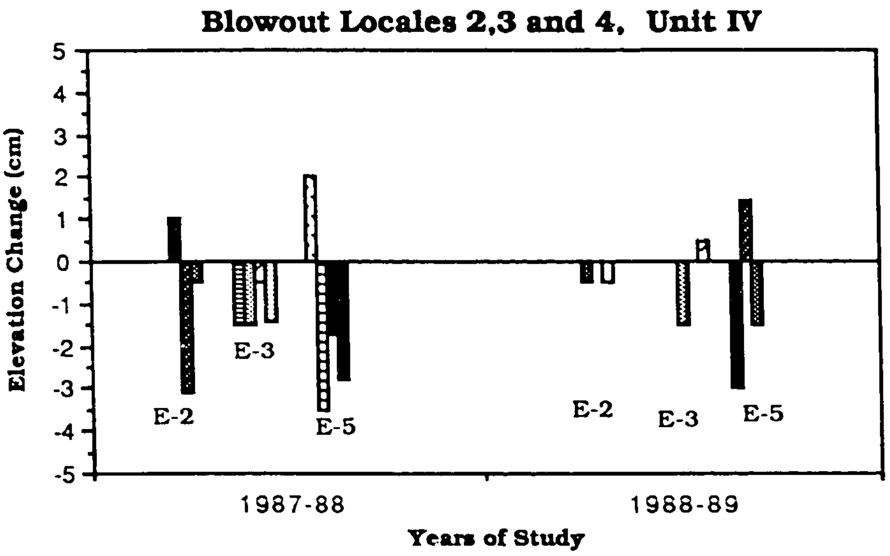

Fig. 3.8 (b). Elevation changes in Espenberg blowouts, 1987-1989. Unit IV ridges E-2, E-3 and E-5.

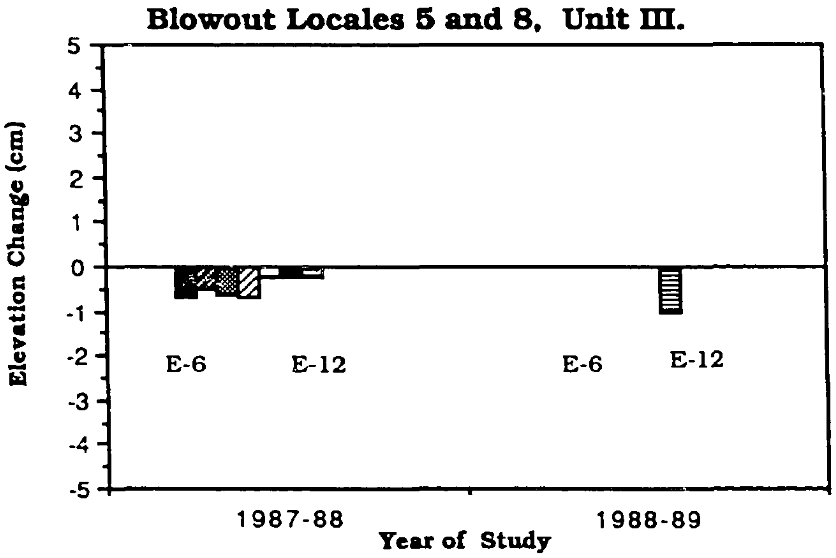

Fig. 3.8 (c). Elevation changes in Espenberg blowouts, 1987-1989. Unit III ridges E-6 and E-12.

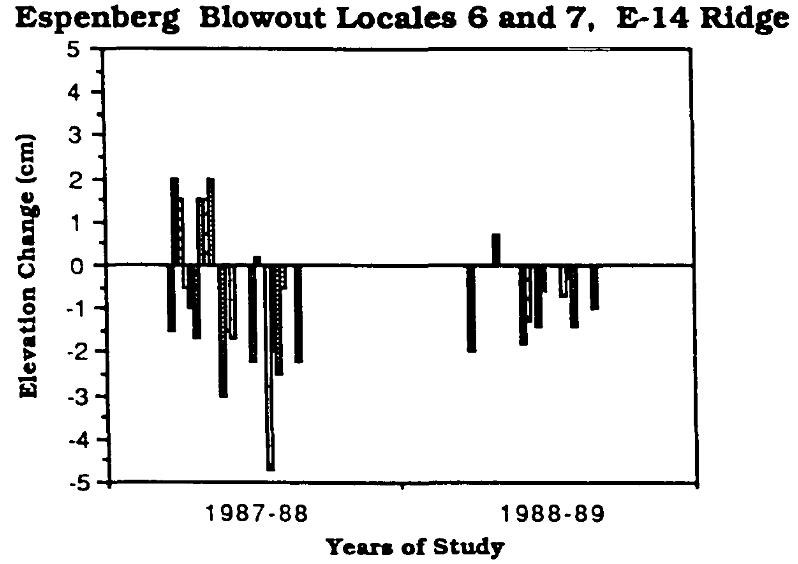

Fig. 3.8 (d). Elevation changes in Espenberg blowouts, 1987-1989. Unit II ridge E-14.

The nature of the vegetation cover provides an index of the degree of sand mobility. Areas with the greatest rates of deposition possessed a complete ground cover of lyme grass, while stable areas had a nearly total cover of crowberry and erodible areas possessed a cover of cinquefoil shrubs. Seasonally ponded areas contained rushes (*Juncus* spp.) and scattered tufts of grass.

Blowout Expansion Processes in the Arctic

The excavation of a blowout depends on several factors, not the least of which are the strength, intensity and seasonality of the wind regime. Maximum erosivity need not occur under the influence of the strongest winds. As found by a Dutch study, winds of 8.75-10 m/sec (about 20-25 mph) were most effective in moving sand (Jungerius et al. 1981:381). Such winds are most dominant at Espenberg throughout the year (LaBelle et al. 1983).

Rainfall does not inhibit sand movement if the rain is accompanied by high winds capable of drying the sand (Greeley and Iversen 1985:85). Hence, the effect of rain is often short-lived, especially if the rain is not intense. Moisture *does* have an effect, however, since sand at field capacity (fully saturated with water) will not move even at wind speeds of 40 m/sec (95 mph) (Jungerius et al. 1981:383). Wind transport may be also hindered if a resistant, frozen surface crust forms during the winter (Jungerius et al. 1981:385) but such surface crusts require an appreciable moisture content unlikely to be found on the dry Seward Peninsula. As noted above, informants report that sand does indeed move during the winter along the Seward Peninsula coast.

Wind erosivity is most intense in the first part of the blowout it reaches: the blowout "throat." Generally, the ability of wind to move sand decreases as it entrains sand within the blowout. Blowouts therefore expand in opposition to the prevailing wind direction, with erosion proceeding most intensely at the throat of the blowout. However, measurements from the Netherlands indicate that wind velocity may also increase after it enters the blowout, swirls about at the base of rims and is unable to leave, leading to deepening. Differences in the effects of wind may be related to the width of the blowout; in narrow blowouts velocity may increase and in wide blowouts it may decrease.

Considerable wind energy may be exerted on the blowout walls. Blowout edges cause turbulence (Seppälä 1984:46), the blowout widens as steep faces recede. As the base of blowout rims is undercut, sand avalanches, flowing down as grainflows or as part of cohesive slump blocks bound by roots. Widening is usually assymmetric due to differing effects of wind on each rim. Erosion on one aspect may be accompanied by accumulation on the other.

In northern regions, another influence on the collapse of blowout walls involves the seasonal moisture gradient produced as snow within the blowout melts. During the break-up period, blowout basins impound water and the moisture stabilizes the lower walls while the upper walls are dry and subject to collapse at the moisture boundary. The discharge of snowmelt through a blowout wall may result in small scale collapse and deposition of alluvial fans. The margins often collapse in blocks because roots bind the upper five to ten cm of the blowout rims. As noted by Cooper (1958:73), the more stable the surface cover of dunes, the steeper the blowout walls. At Espenberg, blowout walls may be nearly vertical due to binding by crowberry, but are less vertical where bound by grass.

Relatively little erosion may occur within the actual basin of the blowout due to the proximity of seasonally fluctuating ground water table. A seasonal or annual permafrost table may effectively perch the water table during the growing season. In 1989, as mentioned above, some of the monitored blowouts contained standing water and little vertical change was observed. Thus, an archaeological site on the blowout floor could be comparatively stable. Transport of sand in and out of the blowout may vary seasonally if a seasonal shift in wind direction or moisture regime occurs (N. Lancaster 1986).

The shape and the length of a blowout are parameters that exert a controlling influence over the scale of erosion. Maximum erosivity occurs in round blowouts, as reported by Jungerius et al. (1981:394) since within round shapes, wind speed remains sufficient to move sand. In long, narrow blowouts, on the other hand, wind speed dies rapidly. Thus, blowout shapes may be visualized as a continuum with two end members: round versus elliptical. Round blowouts are the younger form and elliptical the more mature. Such a distinction may prove useful to the archaeologist encountering a blowout site.

In the Netherlands, the maximum size of blowouts was found to be about 30 m (Jungerius et al. 1981). However, at Espenberg I observed blowouts that exceeded 30 m in length if winds attacked a dune ridge from opposing quadrants of the compass at various times. Complementary but separate blowouts may thus be created, with only a thin baulk between them. The baulk may then collapse to form a single large blowout.

The Cessation of Deflation

Conditions enhancing plant growth or impeding sand transport lead to the cessation of eolian deflation (Stage D blowouts). Increases in moisture within a blowout may occur in several ways. First, deflation may proceed until the pre-existing level of groundwater is reached--or the groundwater table rises. A positive moisture balance may result if precipitation or snowmelt collects within the blowout. The depth of a blowout probably will not exceed the approximate 10 m depth beyond which incoming wind can no longer effectively erode sand (Seppälä 1984:47-48).

Archaeological Sites in Relation to Ridge Geomorphology at Espenberg

As summarized above, the topography of Cape Espenberg ridges is straightforward; two basic types of sand ridges occur (Mason 1987,1988b, this volume, Ch. 2): (1) accretional dune ridges, relatively high in elevation--2 to 3 m above the locally prevailing water table and (2) flat, primary beach ridges only 1 m above watertable, lacking appreciable dunes. Human occupation of Espenberg ridges is most evident on the elevated dune ridges more than 3 m above sea level (Schaaf 1988a, 1988b). People were probably attracted to the Espenberg dunes in order to gain an advantage in sighting game (as at Pt. Hope where sighting stations of wood are built) or to avoid storm surges. Modern subsistence foods obtained at Espenberg include seals, walrus and waterfowl (Sobelman 1985). After break-up and the onset of open water conditions, pack ice may remain grounded on the shoals east of the Cape, allowing people to stalk the basking ringed seals, as in June 1989 (Mason, field notes, 1989).

In late prehistoric times the Cape Espenberg region was sparsely settled. The largest village had a population of only 40 (1880 census) (Ray 1964) and was located at the mouth of the Espenberg River. According to Burch (1980:288), a major societal boundary lay to the west of Espenberg. People living at Espenberg focused on Good Hope Bay (in southern Kotzebue Sound) and visited the Cape primarily for sealing during late winter/early break-up in May to early July. An interest in seals is confirmed by the limited faunal data from the 1988 NPS excavations. Isolated surface finds of whale bones (ribs, mandibles) suggest that whaling crews might have been fielded at Cape Espenberg , although none are recorded during the last 100 yrs.

Archaeological site discovery was greatly furthered by the abundance and size of blowouts (Schaaf 1988b). Older ridges with extensively deflated areas of coalesced blowouts, stage C, reported many more sites than fully vegetated ridges or those with healed blowouts, stage D. Similarly, site discovery was also high on ridges with actively forming blowouts, stages A and B.

Sites in the youngest, high dune ridges are well-defined oval or rectangular depressions, about 4 m in diameter, often linked to side chambers and possessing linear ("arctic") entry ways. House depressions less than 1000 yrs old are generally completely vegetated with crowberry or willow and grass. The density of vegetation in recent depressions indicates that soil nutrients are plentiful as a result of the human debris and construction. Extensive rows (extending several hundreds of meters) of semi-subterranean house depressions are most common only on the E-3 and E-5 ridges. These rows of house depressions, "villages," are readily apparent on aerial photos rendered more visible by the presence of disturbance vegetation.

House depressions on the low E-8 ridge are delineated by the growth of crowberry clones in rectangular outlines, as noted by NPS archaeologists in 1988. Subsurface tests substantiated that occupational surfaces and artifacts lay beneath them (Harritt 1989).

On the high E-14 ridge which is up to 8 m above MSL, the 1986 NPS survey encountered more than 40 archaeological loci in coalesced stage C blowouts. Sites within the blowouts range from isolated finds of single culturally diagnostic tools, scatters of micro-debitage to extensive scatters of ceramics and tools (Schaaf 1988a,1988b). Dated to the third millennium BP (2900-2200 BP) the artifacts reflect an occupation by the widespread Choris and Norton cultures (Giddings and Anderson 1986). The occurrence of pottery usually suggests a relatively sedentary settlement pattern, depending on the portability of the ceramics (Arnold 1985).

The Choris and Norton sites revealed in the extensive blowout regions of the Espenberg are enigmatic. No single site stands apart as a focal settlement, but discrete scatters of ceramics are common. Accompanying these scatters may be several diagnostic pieces such as bifaces (projectile point tips, side blades, etc.), stone lamps, small amounts of lithic debitage, pumice abraders and masses of sand and charcoal cemented by sea mammal oil. Buried anthropogenic surfaces are rare, as are clearly identified house depressions. However, sites, are consistently associated with well-developed paleosols or buried O horizons. It appears that during Choris and Norton times, Espenberg supported only ephemeral encampments of hunters or extremely small nuclear family groups.

The Geoarchaeology of Espenberg Blowouts

To consider site integrity, one must distinguish between (1) sites *excavated into* dune ridges and (2) sites *atop* ridges. As for the former case, the insulation values of subterranean houses, a preference of Alaska Natives, are well-attested and sand is easy to dig. Prehistoric inhabitants of the dunes probably exploited natural cavities such as blowouts, in addition to excavating their own. Building activities extend more than 1.5 m below the surface, on the youngest ridges (Harritt 1989). The potential for finding undisturbed cultural remains is particularly high in these sites. Another distinction should be made between longer term occupations and temporary sites relating to tool manufacture or hunting. Determining the original context of temporary sites may be nearly impossible in blowout sites, for reasons explained below.

Burial sites were sometimes located on high prominences. Several are found on the E-5 ridge, which is now about 400 m from the modern shore. Modern burials are present on the second ridge, placed at some distance from the sea, away from danger of wave erosion. Ancient burials also appear to lie inland from contemporary dwelling sites. For this reason, most burials are substantially younger than the ridges where they are located and provide only distant limiting ages for the deposition of the underlying beach ridges and dunes.

The effect of blowout evolution on the integrity of archaeological sites may be demonstrated by referring to several examples. Conceivably, little change may occur if a house that was excavated into a dune or a pre-existing blowout. This ideal situation would occur only if the occupation is sealed against further deflation. However, if multiple blowouts develop, artifacts may be discharged into one of several directions, complicating the inference of original contexts. An example of the resulting ambiguity is seen in Fig. 3.9 which shows that bones from a single burial have been shed down slope into two adjacent blowouts (Schaaf 1988b:275ff). If the wall separating the two scatters is destroyed, the result will be two scatters, separated by several meters; both derived from a single burial. A similar extrapolation could be made with

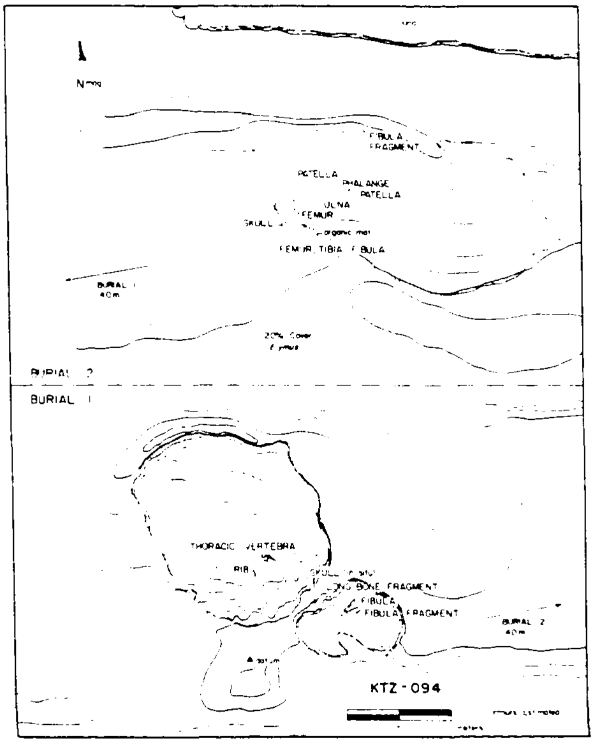

Fig. 3.9. Site map of KTZ-94, Cape Espenberg, showing effects of blowout expansion on the integrity of a dune-top burial (from Schaaf 1988b: 277). Burial 1 (lower) is being shed into two different blowouts, the eventual result will be a chaotic scatter of bone with little relation to the original context.

reference to flint-knapping events or campsites. The net result of many blowout sites will be a chaotic lag, deposited near the erosional limit of the local water table. This will be especially true if sites in the same side wall collapse at different times, as mentioned above.

Side wall collapse may be the most important variable to monitor in blowout sites, although sites in blowout basins may also change with variable wind conditions. Returning to the Espenberg area three years after the 1986 survey, I observed several changes in blowout sites. In KTZ-115 (Schaaf 1988b:331-333), wall collapse revealed a human cranium and several vertebrae. However, in another site, KTZ-127 (Schaaf 1988b:358-360), little change occurred on the blowout basin and the sparse artifactual material remained confined to a 2 cm thick cover of dry, loose sand atop moist, abrupt contact with oxidized sands. Despite collection and screening in 1989, no additional buried artifacts were found (Mason 1989, field notes). Sites in blowout basins are less erodible if the water table is close.

The extent of eolian activity in a blowout may be gauged by the state of the side walls: the weathering state of slump blocks, avalanching of walls and paleosols, which are even more crucial here than in other sites. As mentioned above, vegetation cover controls the verticality of walls: avalanching is more common with grass, straight walls with crowberry or other shrubs. Wall collapse through avalanching will most likely result in artifacts being focused in toward the center of the blowout. Paleosols exposed in the blowout side wall provide the best hope of undisturbed deposits while artifacts at distance from paleosols lack clear context. If a paleosol containing occupational remains is low enough in the wall then lateral continuity is conceivable, but is still unlikely due to the possibility of multiple erosion events.

In 1989, a very small test excavation (0.5 by 1 m) into the wall of KTZ-127 revealed, as expected, that paleosols or buried organic horizons often continue at a slope independent of the trend of the modern surface. Correlation of the same paleo-surface or soil across neighboring blowouts offers the best possibility of finding undisturbed deposits. Hence, extensive survey of neighboring blowouts should be undertaken before excavation.

The height of a dated paleosol within a blowout may allow one to estimate an averaged, cumulative erosion rate. KTZ-079 (Schaaf 1988b:236-238) is located in the 2 m high western wall of a large blowout floored with water-loving plants (ie., rushes). The site had a series of three 1 cm thick cultural horizons, 59-78 cm below the modern surface, but 1.5 m above the basin floor. Plentiful charcoal and burnt wood yielded two ^{14}C dates of 2660 ±110 BP (ß-17961) and 2340 ±80 BP (ß-17962). Hence, about a 1.5 m depth of sand was deflated over the last 2500 yrs or only 0.6 mm per yr, at an averaged rate. The opposing eastern rim of the blowout rises about 4 m above the floor of the blowout and reveals accretion in the lee of the wind as the blowout eroded. Numerous weakly laminated paleosurfaces were evident in this prominence--some of which may correlate with the site horizons. If I use an estimate of 2.5 m of accretion since the 2500 yr old level of KTZ-079, a much higher rate of 1 mm/yr of accretion is calculated.

In many cases, occupations on the older ridges at Espenberg are correlated with paleosurfaces. As in more recent sites, improved nutrient concentrations led to the stabilization of the site surface by plants. At some point, erosion was initiated probably due to plant mortality or animal burrowing or trampling. The common circumstance of multiple paleo-surfaces on older ridges indicates that the erosional process was rapid and the figure of only 0.6 mm per yr is a gross underestimate, as is seen from my own data.

Cultural horizons in blowout walls are likely to contain intact deposits, but all possible topographic dynamics should be considered before the facile assumption is accepted. By and large, however, blowouts must be regarded as a disturbed context until proven intact because numerous processes may result in the concentration and focusing of artifacts within the center of the deflation hollow.

Artifact Visibility and Dispersal in Blowouts

Two recent South African studies provide some guidelines for conducting archaeological studies in blowouts. Examining purportedly stabilized archaeological sites in deflation hollows, N. Lancaster (1986) found a significant seasonal component in artifact visibility, with considerably more visibility during periods of erosive winds. Thus, it is advisable to survey during peak windy periods and to examine the climatic patterns of a region before undertaking survey. The converse is also important--on surveys during periods that are particularly calm, fewer artifacts may be exposed. To test ideas about site formation processes in eolian sites, J. Lancaster (1986) placed weighed amounts of replicated lithic debitage on different aspects of a blowout near Cape Town. On a revisit of the site after a windy episode of 5 days, the lithic fraction remaining was photographed and re-weighed. In the location with rapid deposition in the lee portion of the blowout, substantial integrity was maintained. However, in the erosive windward and basinal portions of the blowout, loss of many size ranges was common. About 40% of lithic fragments less than 1.6 mm (0.063 in) were "lost" to deflation. Of course, such size ranges probably elude most archaeologists, if controlled excavations use the standard 1/8" (3.175 mm) mesh screen.

Conclusions: Implications for Archaeologists

Two years of record show that Espenberg blowouts are particularly active. Even if 1987-1989 were peculiarly erosive years, the amount of vertical change within a blowout could seriously alter or even "threaten" an archaeological site enclosed within a blowout. The discovery of a skull eroding from a blowout wall, noted in a re-visit three years after the original 1986 site mapping also serves as a caution. One implication for blowout archaeology seems clear: maps themselves are especially transitory items. Further, since blowout changes may be frequent, sites continue to be modified in an unknown fashion and this should encourage land managers to undertake total mitigative work to document the presently known sites before further disruption occurs.

The quantification of geomorphic processes provides insight into microscale climatic controls over erosion and data for practical applications for land managers. The Finnish researcher, Sepällä (1984), used calibrated stakes to quantify blowout erosion over four yrs (1974-77), reporting that up to a 10 cm thickness of sand eroded annually in the blowout basin (as opposed to the walls). Jungerius et al. (1981) used similar methods in the Netherlands to measure up to 100 cm of erosion during a two yrs within seven blowouts in "De Blink" region. Blowout erosion was associated with winds in the 8.75-10 m/sec class as blowouts expanded due to mass wasting associated with the undercutting of walls. In coastal New Jersey, Gares and Nordstrom (1987) discovered, as a result of a multi-year study, that blowout walls undergo greater changes than the floor and that gaps in foredune heighten the loss of sand from the dune area. Similar findings, indicating little modification in the centers of blowout basins, are reported by N. Lancaster (1986) in a geoarchaeological study of blowouts near Elands Bay,South Africa. At Cape Espenberg, as in Finland, significant blowout erosion, up to 10 cm per annum, occurs as basins deepen. Wall collapse, though unquantified in my study, seems to be a slower process, more episodic, resulting through undercutting and collapse of root-bound blocks. In regard to long-term rates of blowout evolution, at Espenberg, change is most rapid on the youngest, best drained ridges and slows considerably on lower ridges which are closer to water table.

The presence of paleosurface indicators such as buried organic horizons or paleosols are an important referent for archaeologists working in blowouts. First and foremost, such horizons define an earlier topography which is unrelated to the observed present topography of blowout ridges. Archaeologists must should determine the lateral extent and vertical variability of these surfaces to obtain accurate site context. At Espenberg, fairly abundant charcoal concentrations were often encountered within paleo-surfaces, counteracting the preconception that charcoal should be ephemeral in the "ever-shifting sands" of coastal dunes.

The preservation of organic remains such as bone and wood diminishes rapidly on ridges older than 1000 yrs at Espenberg, though for unknown reasons. Animal burrows are quite significant on older ridges; however, such disturbance is comparatively rare on the younger ridges. Perhaps, the disruption of ground cover is necessary before burrowing animals can locate bone.

Questions for Archaeologists:

What can archaeologists learn from the geomorphology and sedimentology of blowouts? The following list of questions may be useful:

(1) When encountering a site locus within a blowout, special attention should be paid to the vegetation cover. Does one find species such as rushes (*Juncus* spp.) which are favored by seasonal ponding? Does the base of the blowout intersect the water table? Does the sand bear any evidence of oxidation? A positive answer to these questions would lead one to expect that the blowout is comparatively stable at present and will not undergo further eolian deflation.

(2) What is the size and shape of the blowout? Recalling that round blowouts are probably still susceptible to substantial expansion, investigation of a site in a small, circular blowout should have higher priority than an archaeological lag deposit likely in a larger, more oblong form. How deep is the blowout? Remembering that the effective erosivity of the wind extends down to about 10 m, one may assess the probable extent of future erosion. Once again, priority should be given to a possibly intact archeological in a side wall over a basin lag deposit.

(3) Are paleosurfaces exposed in the walls of the blowout? How does the site relate to this surface--is there evidence for recent wall collapse? Measurements of the slope of buried paleosurfaces will reveal the previous topography of the dunal landscape.

(4) What is the condition of the walls of the blowout? Have they slumped recently? It is helpful to distinguish between collapse of undercut masses that are re-deposited intact blocks held in place by sod and the avalanching of large amounts of dry sand. Artifacts lodged in paleosols or even blocks are, of course, more readily related to their original provenience than are those from avalanche deposits.

(5) Where is the "throat" of the blowout? In other words, what winds are responsible for eroding the blowout. Measurements of blowout orientation may provide some idea of the prevailing wind direction in the region.

Upon encountering archaeological sites in the walls of blowouts, archaeologists should note the size, shape and depth of the blowout in order to assess its potential for future expansion. An idea of blowout stability, including the likelihood of seasonal ponding, may also be gained by examining the prevailing vegetation cover. As elsewhere, paleosols should be noted closely, with particular reference to their position in blowout walls.

If possible, archaeological survey in blowout areas should be planned for months when wind deflation is maximal. If surveys are conducted in calm months, investigators should expect to find less dense artifact clusters.

It is important to regard the blowout environment as a potentially active one. However, mapping of paleosols exposed in clusters of blowouts may allow a better perspective on associated blowouts. Correlations of such paleosurfaces may also assist in establishing histories of eolian deposition and deflation which in turn may or may not be correlated with climatic changes.

Chapter 4

The Gravel Beach Ridges of Choris Peninsula:

A Holocene Storm History Correlative

with Cape Espenberg.

Introduction

Beach ridges, abandoned strandlines or storm ridges, in Johnson's (1919) definitions, provide a repository of paleoenvironmental data closely related to trends in global wind and climatic patterns. Researchers use well-dated beach ridge complexes to study shifts in Holocene storm intensity (Thom 1978), sea surface temperature variations (Richardson 1983, Sandweiss 1986) and the relative positions of the Arctic Front (Moore and Giddings 1961). By using radiocarbon chronologies obtained from archaeological data, it is possible to correlate beach ridge deposits from adjacent coastlines and obtain a regional climatic record. The ridges at Choris described here contain a proxy record of late Holocene storm climates.

The northwest Alaskan coast has seven beach ridge complexes formed at critical coastal orientations as coastal currents lessen and deposition is favored (Fig. 2.1). Archaeological research on one of the complexes on Choris Peninsula by J.L. Giddings (1967) in the late 1950's led to the development of the beach ridge dating method and the impetus to survey and date other beach ridge complexes, especially Cape Krusenstern (Mason this volume, Ch. 1). Giddings and his geological co-worker George Moore did not correlate deposits from two or more beach ridge complexes, but postulated that wind and climate controlled their sedimentation (Moore and Giddings 1961). In the thirty years following Giddings' work, little further research was conducted on Kotzebue Sound beach ridges until my own in 1986-89. My research on the beach and dune ridges of Cape Espenberg, described in Chapters 2 and 3, suggests that the Chukchi Sea experienced heightened storminess during discrete periods of the late Holocene: from 3300-2000 years BP and at intervals 1200 years BP to the present. The following examination of the sedimentology and history of gravel ridges at Choris provides a test of my conclusions for Cape Espenberg.

In applying the geoarchaeological approach used at the Cape Espenberg beach ridge plain to Choris, it is necessary to realize that sand and gravel respond differently to storm wave climates (Shepard 1973:127,Wright et al.1979, Orford 1987). Energy dissipative beach profiles are common in fine to very fine sands and result in nearly level slopes of only 1°-3.° Such flat beach faces damp the energy of storm waves but allow greater landward penetration of waves. The development of foredunes, washover deposits and transgressive dunes is favored within sandy materials. Gravel forms higher, steeper (up to 24° in the case of cobbles) energy reflective beaches, allowing waves with greater amplitude to break closer to the shore. The high angled gravel beach forms a ramp and clasts are pushed up to the crest (Carter and Orford 1981, Orford and Carter 1982). Since only storms with the highest energies can drive clasts up the beachface, the gravel system is able to absorb numerous smaller storm events without producing a distinctly new ridge. Hence, the process of constructing a gravel ridge involves the cumulative effects of numerous high magnitude storms. The amount of time involved in this process is well-documented at Safety Sound where the same ridge contains stratified archaeological materials of about 3500 yrs old and 2400-2000 years old (Bockstoce 1979:19-39).

To reconstruct the depositional history of Choris Peninsula beach ridges, I use the same geoarchaeological methods as at Espenberg (Mason this volume, Ch. 2): aerial photo interpretation, vegetational and topographic differences between the ridges, available radiocarbon dates and archaeological data, and stratigraphic evidence. As at Espenberg, I placed shovel probes 50-80 cm deep along transects parallel to Choris ridges, making detailed profile notes and photo documentation. Limited samples were collected for grain size determinations and provenience studies. I also described modern beach facies at Choris. Archaeological investigations by Giddings (1957, Giddings and Anderson 1986) provided diagnostic artifacts and radiocarbon dates useful in establishing a chronology. I conducted a brief archaeological survey along the bluff margins of eastern Choris Peninsula. In addition, my work benefited from archaeological site mapping conducted in 1987 by the ANCSA (Alaska Native Claims Settlement Act) office of the Bureau of Indian Affairs, Anchorage.

Research Aims

I conducted research at Choris in order to:

(1) Describe sedimentary processes in an arctic gravel beach ridge system;

(2) Obtain chronological data useful in correlating the depositional record at Choris with that of Cape Espenberg;

(3) Link sedimentation at Choris to the climatic history of Northwest Alaska.

Study Area: Topography and Delineation of Choris Peninsula Beach Ridge Complexes

Located on the eastern shore of Kotzebue Sound, the 5 km long Choris Peninsula (at 66°16'N., 161°50' W.) issues from a narrow isthmus connecting it to the sinuous Baldwin Peninsula, which divides Hotham Inlet from Kotzebue Sound (Fig. 4.1). To the east, Choris Peninsula itself encloses Eschscholtz Bay, a smaller, shallow (10-15 m deep) embayment of Kotzebue Sound. To the south, Chamisso Island lies across the 2 km wide Chamisso Anchorage, a good anchorage used by Euro-American explorers. The rhomboidal southern portion of Choris Peninsula is a bedrock bluff rising 112.5 m in its north-central portion, with 50 m steep cliffs on all sides. The bluff is saddle shaped topographically; it rises in the north and south and has a general slope to the east. The eastern slope is amphitheater shaped, containing a thick tussock tundra cover draining into two small thaw lake ponds. The ponds are the source of a small creek which drains to the east, crosscutting a beach ridge complex facing Eschscholtz Bay.

Three former embayments on differing aspects of the Choris Peninsula are now filled with beach ridge complexes (Fig. 4.1). I assigned the different beach ridge complexes alphabetic designations (A, B, C) as an aid to discussion and cross-correlation. The complexes were labelled counter-clockwise from the southwest to

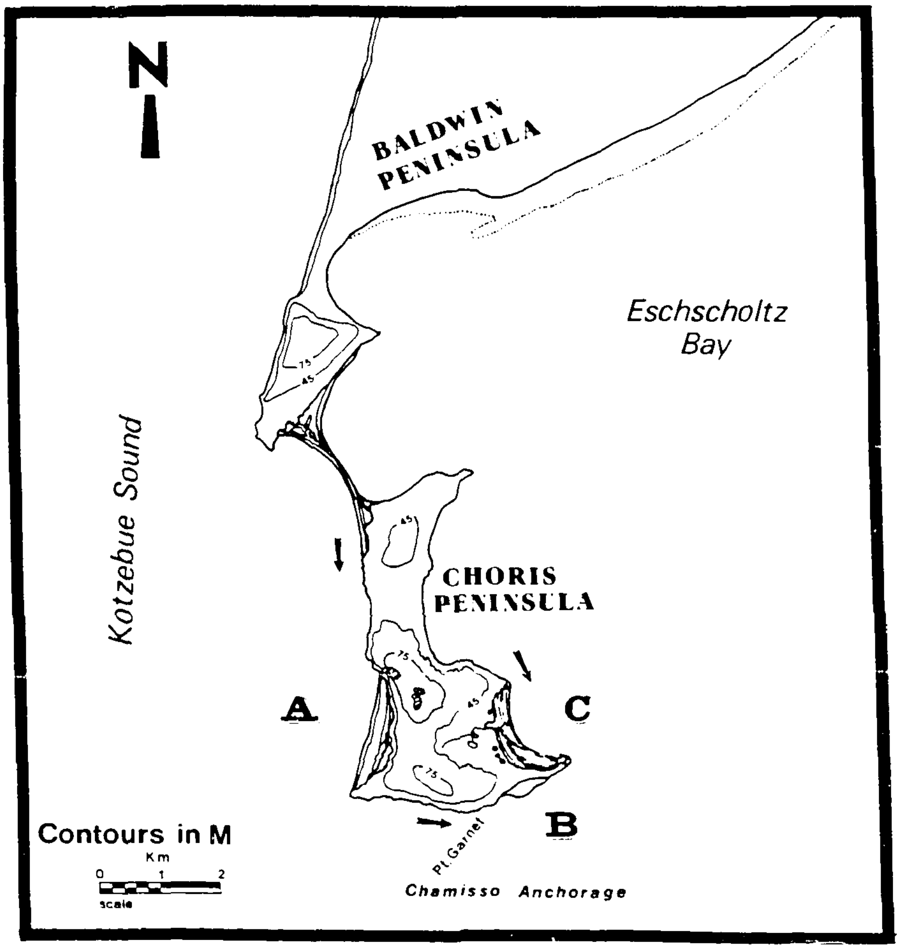

Fig. 4.1. Map of Choris Peninsula. Beach ridge plains formed in three former embayments, labelled A, B and C. Arrows indicate prevailing longshore transport direction.

northeast (Figure 4.1).

The southwesterly ridge complex A contains nine distinct, broad ridges, while the other two complexes contain more ridges--based on examination of an enlargement (10x) of a high altitude (U-2) 1:62,500 aerial photo, obtained from the Geodata Center (University of Alaska). Giddings mapped the A complex ridges (Giddings and Anderson 1986:21) but he did not map or quantify the number of ridges on the other ridge complexes. The B complex possesses 10 ridges while the C complex has 15 ridges or ridge fragments. Three depositional units are tentatively identified on each of the Choris complexes.

The Choris Peninsula attachment to Baldwin Peninsula is narrow strip of beach sediments--a tombolo, less than 100 m wide (Fig. 4.1). If this tombolo did not exist or were breached, Choris Peninsula would be an island. Indeed, the formation of the tombolo may provide a preface to the history of the beach ridge complexes on Choris. If sediment is being transported north to south then the tombolo must have formed as sediment was brought to Choris. Based on vegetational differences, two distinct sedimentary units are distinguishable on the tombolo--an older cycle of deposition from the west and a younger from the east. This temporal distinction may be useful in deciphering the history of Choris itself.

Source Materials: Geological Setting

The Baldwin Peninsula, an appendage of the mainland to the north of Choris, is composed of Middle Pleistocene glacio-marine and loess deposits (McCullough et al. 1965, Patton and Miller 1968, D. M. Hopkins 1990, personal communication). By contrast,Choris Peninsula consists of much older metamorphic rocks and is divisible into two parts: (a) in the north, a rectangular mass of middle Paleozoic limestone and dolomite, interbedded with phyllite and schist and (b) in the south, a rhomboidal knob also of middle Paleozoic aged mica schist and schistose quartzite (Patton and Miller 1968). Schist clasts over 15 cm (largest, 42 cm) in length are common on the modern beach and confirm that local bluff erosion is providing some of the clasts (Mason 1987, unpublished field data). However, the chert cobbles of non-local origin indicate that some beach clasts derive from distant updrift bluff erosion or offshore sediment sources, an unlikely possibility.

Offshore Sediments and Longshore Transport Directions

Kotzebue Sound bottom sediments offshore from Choris Peninsula are coarse silt (4-5ø) and fine sand (3-4ø) (Creager and McManus 1966). While sand is a significant component of most of the ridges, the offshore silts are non-erodible and are not re-mobilized onto land. The most prevalent clast sizes on the beach ridges are pebble (-1 to -6ø) and cobble (-6 to -8ø), quite larger than are available offshore. The source material for the ridges, therefore, is the adjacent terrestrial bluffs. The eroding Baldwin Peninsula bluffs are the most important source for Choris clasts. These bluffs consist of glacio-marine sediments and are the source of some exotic materials, e.g. , red and black chert cobbles.

The direction of transport within individual Choris complexes may be inferred from the provenance of clasts, the bifurcation pattern of ridges and trends of spit formation. Within the Choris A complex, clasts are derived from the Baldwin Peninsula bluffs, about 10 km to the north (Fig. 4.1). The transport direction results from a net southward longshore drift, as evident from the spatial and topographic pattern of the beach ridges themselves. First, on the surface, the ridges in the A complex merge in the south, (Fig.4.2). A series of elevational transects measured by Giddings (Fig.4.3), the height of the youngest ridge also increases about 1 m southward, reflecting either greater wave energy input or the inability of southward transported materials to bypass the southwest promontory of Choris Peninsula. The cul-de-sac nature of this area may produce the merging of ridges, which also indicates the vertical thickening of the sediment wedge. I observed a series of three offshore bars southwest of the Choris B complex, in the process of onshore migration (Mason, unpublished field notes, 1987), indicating shoreward transport from the westerly direction, with marked deceleration east of Pt. Garnet which favors deposition in the B complex.

For the eastern side of Choris Peninsula, the C complex, northern sources again predominate. Eroded bluffs on the north shore of Eschscholtz Bay also contain abundant Pleistocene loess and sands (Quakenbush 1909) and form tidal flats. These fine sediments are mobilized southward and deposited in the C complex of Choris. Within the Choris C complex, the ridges are deflected by the discharge of a small stream which issues from the interior of the peninsula and the southern portion of the C complex encloses a small estuary. Ridge propagation has followed north to south (Fig. 4.1)

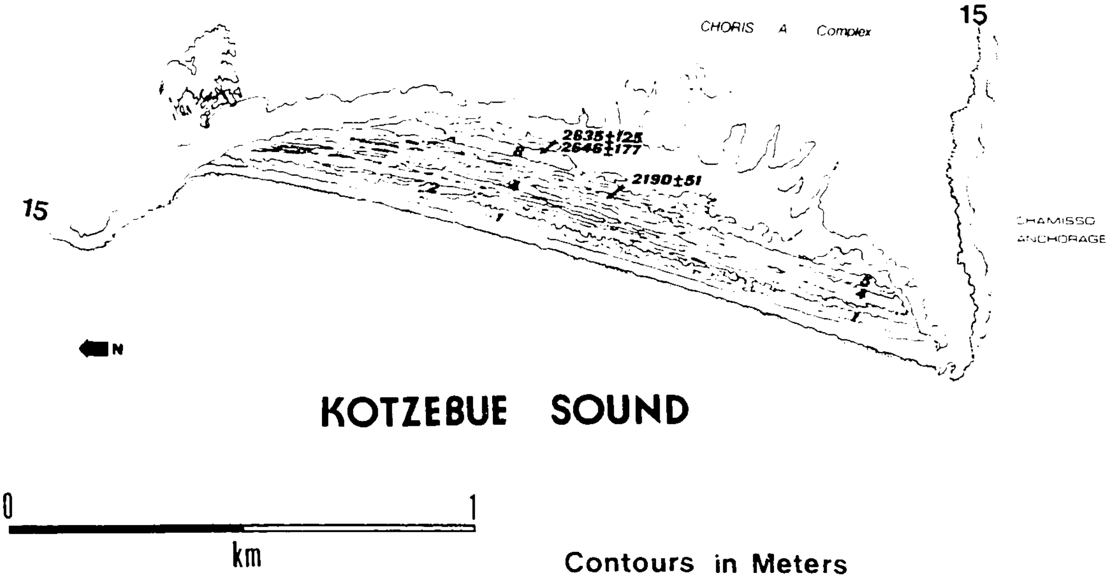

Fig. 4.2. Map of Choris Peninsula A complex, on the southwest part of the peninsula. Radiocarbon dates are from Giddings' excavations (Giddings and Anderson 1986:30). Ridges are numbered increasing landward, following Giddings (1963).

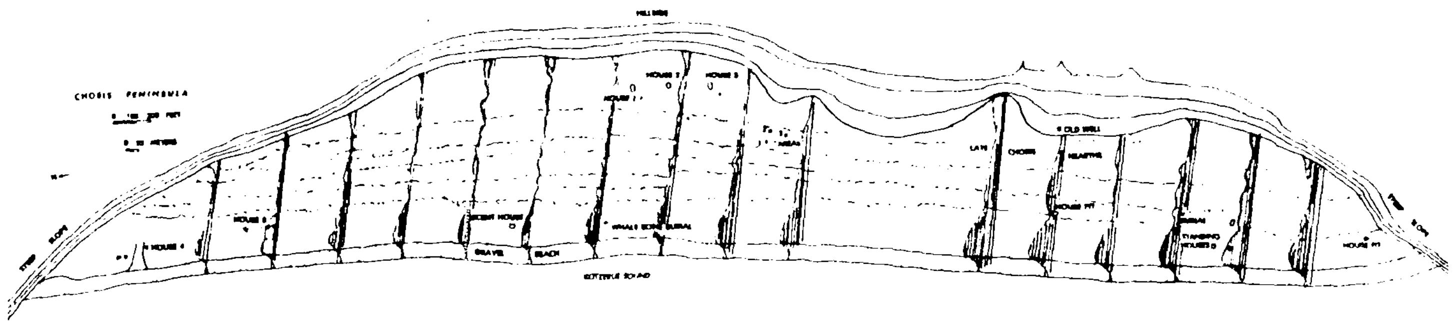

Fig. 4.3. Map of elevational transect across the Choris A complex, from Giddings and Anderson (1986: 20-21). Note that the most seaward ridge, A-1, is highest and widest in the south. North is to the left on the page.

Choris Peninsula Beach Ridge Complexes

Methodology

For the most part, it was necessary to excavate shovel probes to describe strata emplaced during the construction of the ridges and to collect sediment samples for granulometric assessments and to attempt to obtain organic samples for radiometric dating. Field work also included the examination of cutbank profiles on the most recent ridge, the description of modern beach facies and the measurement of largest cobble size and lithology on the modern beach. I counted the 20-25 largest clasts on different parts of the beach within 1 m^2 areas.

North/South transects were conducted on ridges 1, 4 and 8 of the Choris A complex. Shovel tests up to 80 cm deep and 50 cm^2 were placed at intervals of about 200 m, avoiding private property on the southwest corner of the complex. Shovel probes involved stratigraphic profiling, Munsell readings, photo-documentation and sample collection, if deemed necessary, at each site. No cultural remains were encountered in subsurface tests, but four lithic artifacts were collected from surficial deposits from on or adjacent the A and C complexes; these are temporarily accessioned to the University of Alaska Museum (Fig. 4.4). The efforts of archaeological mapping by the BIA-ANCSA team aided in documenting surficial archaeological occurrences.

The means used to date the Choris beaches includes both relative and radiometric methods. Characteristics such as soil horizon development, weathering rinds and frost hummock development were documented. Though two ^{14}C assays obtained by J. L. Giddings in the 1950's (see below) bracketed the ages for the earliest ridges on A complex, additional assays would have been helpful. In this endeavor the sidewalls of Giddings' excavations were examined and profiled. Though discolored zones of pedogenic and/or cultural origin are evident in the sidewalls, no charcoal or midden concentrations were observed.

Southwest Choris: Complex A

The Choris complex A, located on the southwest part of the peninsula, extends about 2 km north to south and is 300 m wide. The complex contains nine ridges (Fig. 4.2). The modern beach is comparatively steep, rising almost 3 m over its 35 m width.

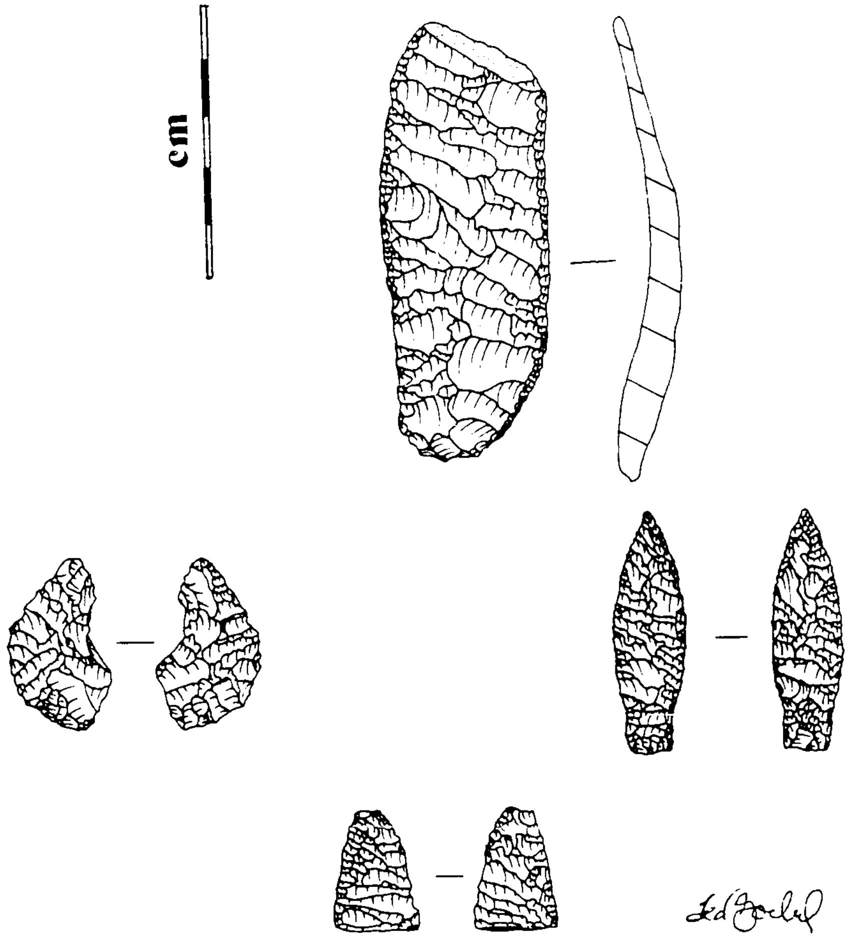

Fig. 4.4. Artifacts collected from Choris Peninsula in 1987, temporarily accessioned to the Univ. of Alaska Fairbanks Museum. Flake scraper (top) is from the A-4 ridge and is related to the ASTt or Choris cultures (Table III) anomalously old for this ridge. The biface (lower) was collected from a bluff atop the A complex, and is assigned to ASTt. The endblade and side blade (middle row) are from SLK-80, a site discovered on the C-15 ridge, the oldest ridge of the C complex. Though undated these artifacts are from either late Choris or early Norton cultures, providing an age estimate of about 3000-2000 yrs for the deposition of the ridge.

In profile, the A complex resembles a dish: the second oldest and the youngest ridges are higher than the middle ridges (Fig. 4.3). Vegetational differences allow the easy delineation of the most seaward, sparsely grass-covered ridge from the remainder of the ridges. This ridge is about 4 m in elevation and nearly 100 m in width--about 1/3 higher and over twice as wide as any of the other ridges. Lyme grass (*Elymus* spp.) and beach vetch grow densely on the seaward aspect of the ridge and decrease exponentially in density landward over the ridge. The sparsely vegetated region marking the landward edge of the first ridge may correspond to the most landward penetration of the last major storm overwash of the A complex. The A-1 ridge slopes gently landward for about 55 m and is bounded by a slight scarp on a very shallow, 30 cm deep swale.

Older ridges on Choris A complex are vegetated by crowberry (*Empetrum nigrum*) and cinquefoil (*Potentilla* spp.) and are ruptured by polygonal nets resulting from cryogenic contraction processes. Thick organic soil horizons occur only on the very oldest ridges (A-8 and A-9) and atop swales as seaward as A-2/A-1. The widths and spacing of Choris ridges and swales are generally consistent across the complex, except for the wider first and eighth ridges, which contain the most significant archaeological remains.

The central portion of the A complex is flat, 2.2-2.5 m above MSL with ridges (A-2 to A-7) about 10-20 m in width. Extensive areas on the ridge tops are unvegetated and polygonal nets are common. Swales, by contrast, are well-vegetated with crowberry but also are crossed by polygonal nets. Swales are only about 30 to 50 cm lower than ridge tops. The A-8 ridge, the Choris ridge, is broader (about 35 m) than any other ridge, except the first (A-1) ridge, and but is only slightly higher than other ridges: 2.6 m above MSL. The oldest A-9 ridge is 2.4 m above MSL in elevation and is fairly narrow, The first colonization of the ridges by blueberry, reflecting its nearness to the bluff edge and increased groundwater flow.

The development of polygonal features begins as recently as the first swale A-1/A-2 at Choris. Polygons on the A-1 to A-4 ridges range in width from 4.5 m to 7.5 m with a trough depth of about 20-30 cm. Polygonal nets increase in size from north to south on the A-4 ridge. A more dense net of smaller, 3 m wide, polygons is evident on the A-8 ridge. The southern portion of the ridge complex is intensely disrupted by frost boils on the surface. The churning effects of this cryogenic process is also revealed in profiles. Thus, the high density of known archaeological loci within the A-2 to A-5 ridges should be viewed with caution and this distribution may not accurately mirror prehistoric use patterns, but only the ability of cryogenic processes to disturb the vegetation cover and render sites visible.

The bluffs bordering the A complex are deeply gullied at the southeast margin. A massive colluvial wedge of sediment has eroded from the gulleys and overlies ridges A-9, A-8 and A-7. I conducted limited exacavation in this area to determination stratigraphic relations and to determine the grain size of the sediments.

Modern Beach Facies on Choris A Complex

The modern Choris beach is steep, rising about 1.6-2.0 m over its average 35 m width. Four to five distinct, coast parallel lines or ridges of gravel and sand occur along the beach. The 10-75 cm high ridges are 1 to 2 m wide and are separated by 2 to 3 m wide troughs. Moving landward, ridges have increasingly larger clasts on the surface. The largest clasts on the most seaward ridge are 3-5 cm length while on the third ridge the largest clasts are 10-15 cm long. Fine to medium sand and small drift wood accumulates in troughs behind the third and fourth landward ridges, about 10-20 m from the beach. Sand is also interbedded between gravels on more seaward ridges.

Crescent shaped piles of sand and small cobbles (3-5 cm diameter) are also common on the upper beach and form as ice ridges are forced onto the beach (Hume and Schalk 1964, Greene 1970). These Choris ice push features were only 15-20 cm in height, 60 cm diameter and were open toward the sea, where drift wood collects. Though not as high as ice push features at Nome or Barrow, the Choris ice push mounds provide some indication of winter ice movement onshore during the 1986-1987 year previous to my visit. I also observed a boulder over 1 m in diameter on the lower beach, certainly transported there by ice-rafting.

My observations on the beach of the Choris A complex parallel the British gravel ridge facies described by Bluck (1967:154ff). Like Bluck, I noted alternations between a large disc, an imbricate zone and an infill zone at the low energy swash zone. The zones have different clast sizes and spaces between clasts, ie. porosity. The larger, disc shaped clasts tend to be concentrated on upper portions of the beach because the rod or egg shaped forms are more susceptible to transport by wave energies. In effect, the rod shapes are moved landward and the discs are left as a lag. In addition, the large pore space in the large disc zone allows the winnowing and concentration of smaller clasts in the lower beach or at subsurface. The seaward slope of the gravel beach is formed by a framework of imbricate clasts that has a step-like appearance. Consequently, the gravel beach is divisible into a high energy upper zone and a lower energy swash zone with an inverse grading the result.

Beach Ridge Stratigraphy--Choris A complex

The clast size of the Choris A deposits is fine and coarse sands to small pebbles and cobbles (5-7cm in diameter). In general the upper facies of most ridges was finer than that at depths. Sedimentary units lower than 50 cm below surface were frequently clast supported small pebbles. Fine and coarse sand beds (of about 10 cm thickness) commonly capped ridge and swales. A sequence of coarsening upward small pebble beds often was succeeded by coarse and fine sand beds of several cm thickness (Fig. 4.5). The succession of these sedimentation units is a swash ramp facies, as defined by Orford and Carter (1982:269ff), and form as clasts are carried up the beach during high energy storms.

Grass beds 1-2 cm in thickness often separated depositional units and were observed in nearly all ridges and swales. Many of the grass beds could be traced in the same ridge following the trend of the complex. Using this stratigraphic marker, I monitored clast size within a single bed of the upper facies of the youngest ridge. In laterally traceable units, gravels and small cobbles occurred in the north parts of the A-1 ridge, while coarse and fine sands predominated in the south, in the direction of longshore transport (Fig. 4.5).

Some depositional units were indurated and slightly normally graded while others were inversely graded. Differences in wave energy account for the two patterns and resemble the modern beach facies. Many of the thin sand beds between small gravels result from the winnowing effect observed on the modern beach. Sand beds more than 10 cm thick are possibly eolian in origin (Fig. 4.5). The inversely graded beds parallel the modern beach facies where less movable discs are concentrated at the uppermost parts of the beach. I encountered clasts as large as those on the modern beach in my shovel probes on older Choris ridges. Partly this reflects the limitation of shovel probes. In one case, I was able to dig about 1.5 m below the surface of the A-8 ridge, by digging into Giddings' unbackfilled excavation pit into Choris house 3 (Fig. 4.6). This test revealed a succession of clast supported coarse sand to granule beds of 10-15 cm thickness separated by more sandy beds organically stained with some rootlets.

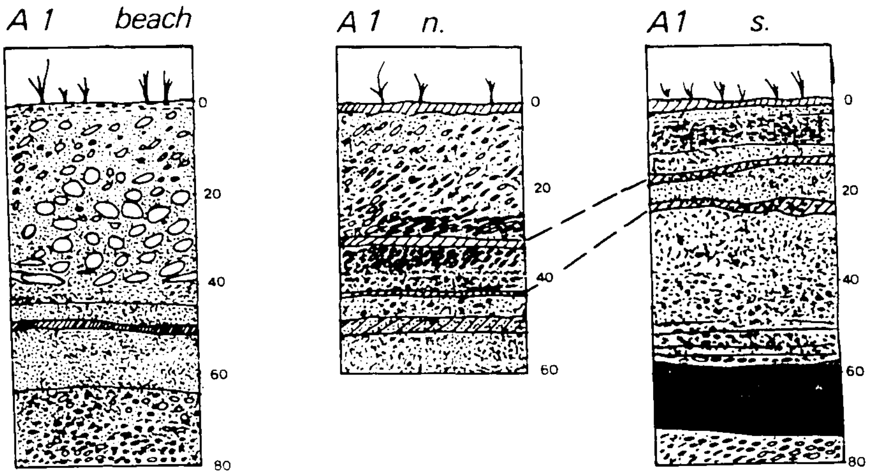

Fig. 4.5. Stratigraphic profiles across the A-1 ridge, Choris Peninsula. Grass beds may be traced laterally across the entire ridge, allowing tentative correlation of sedimentation units. Clasts within a single unit are coarser in the north.

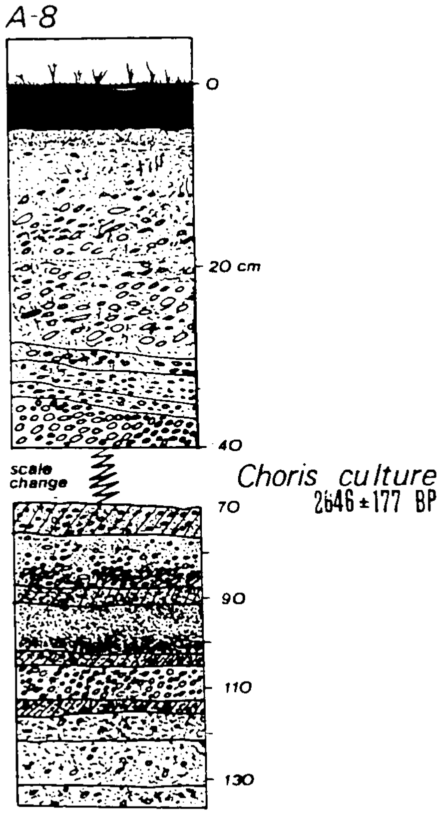

Fig. 4.6. Composite stratigraphic profile in A-8 ridge, Choris Peninsula. A thick organic, silt rich bed caps the ridge, which is composed of a succession of clast-supported or matrix-supported gravel and sand beds. Grass beds represent former stabilized surfaced transgressed by storm deposited gravels. Larger clasts in the upper 50 cm indicate a renewal of storm activity after the Choris occupation, dated at 2646 ±177 BP.

The entire test showed an inverse grading, coarser at the top (Fig. 4.6). Depositional units on the oldest ridge are bracketed by thin (1-3 cm thick) laterally continuous beds of grass and other plant macrofossils. Though such organic rich zones could yield sufficient organic matter for accelerator dating, I did not collect any fragments, lacking the substantial budget to use this dating technique. No shell was observed on older beaches or within stratigraphic contexts. Since the dominant clasts of pea gravel size (2-4 mm in diameter) and larger could only be deposited by marine agencies, it is clear that each ridge represents many discrete events, in light of the numerous grass beds which represent a hiatus in beach ridge addition. Some depositional units reflect the waning phases of a single event. About ten distinct overwash events were involved in constructing the upper 1 m of the A-8 ridge (about 1/3 of its total height). As evident by the increase in clast size, storm energy appears to have increased after the Choris occupation 2650 BP (Fig. 4.6).

In this regard the height of ridges is important since deposition could cease only when the ridge is higher than the possible reach of the sea. However, the sand cover at the surface of many of the ridges may represent wind induced overbluff deposition from the beach.

Examination of the colluvial deposits capping the oldest ridges of the A complexes revealed a thick peat at about 15-30 cm below surface capped by unoxidized silt and also overlies silt. Since permafrost was encountered at about 65 cm below surface, further excavation was not attempted. A systematic trenching program undertaken over a period of several weeks would probably be required to establish the history of the colluvium. In sum, then, the presence of a silty cap on the colluvial deposit indicates intense erosion after the formation of the oldest ridges in the Choris A complex.

Archaeology on the Choris A Complex: Implications for Dating its Depositional History

The archaeological stratigraphy of the A complex records at least four cultural periods: Choris, Norton, western Thule and late prehistoric, as described by Giddings (1957) and Giddings and Anderson (1986). Giddings visited Choris in 1956, 1958 and 1960 (Giddings and Anderson 1986:3ff, 20-21, 187-208). In all, Giddings excavated five house depressions, including three representing the Choris culture and two of late prehistoric western Thule affinities.

The principal Choris occupation lies on the second oldest A-8 ridge. The Choris houses are over 8 m in length and are culturally distinctive in their oval plan view, outlined by postmolds. The recovered cultural inventory is rich in organic materials and provides evidence of a specialized seal and caribou hunting economy. Distinctive artifacts include oil lamps, decorated barbed bone harpoon sockets, bone needles and decorated ceramics. The Choris site (SLK-007) is the type locality for the Choris culture, widespread throughout northwest Alaska (Anderson 1984, Giddings and Anderson 1986).

Radiocarbon dates on the Choris occupation on ridge A-8 span a range of several centuries. In Choris House 1 wood yielded a date of 2635 ±125 BP (P-96) (2753 cal BP) and another sample on antler dates 2244 ±133 BP (P-175) (2248 cal BP). The charcoal date from Choris house 2 at 2646±177 BP (P-203) (Ralph and Ackerman 1961) is concordant with the wood date. If we discount the date on antler as possibly inattentively pre-treated to remove contaminants (Taylor 1987:61), the Choris occupation dates between 3000 BP and 2292 BP, using a 2 sigma range. A cache pit on the A-6 ridge yielded a date of 2190 ±51 BP (Stuckenrath et al. 1966). Considered late Choris by Giddings and Anderson (1986), the cache pit appears to be only slightly younger than that on the A-8 ridge, suggesting that accretion sped up considerably after the principal Choris occupation.

A high density of archaeological loci occurs on the southern portion of the A-4 and A-5 ridges. However, in view of the extensive cryogenic frost boils in this area, this density may not reflect prehistoric reality. The A-4 ridge should date from after 2000 BP and probably before 1000 BP. Otherwise, most the diagnostic artifacts observed on the A-4 ridge fall either into the Norton or Ipiutak culture(s):tapering, unstemmed lanceolate projectile points, with no potsherds on the surface. One unifacial scraper was found and collected because it appears to be more characteristic of Choris materials (Fig. 4.4). The occupations on the 4 m high A-1 ridge contain abundant evidence of a comparatively recent nature: still standing sodhouses, house depressions, wood, gravemarkers and other artifacts, including metal.

Interpretation

The horizontal stratigraphy of the Choris A complex shows a contrast between the wider A-8 and A-1 ridges and the slightly lower and narrower A-2 to A-7 and A-9 ridges (Figs. 4.2, 4.3). On this basis, I define four depositional units at Choris A: **Unit I**, an early period consisting of the A9 ridge at the base of the slope; **Unit II**, the Choris ridge; **Unit III**, the A-7 to A-2 ridges; and **Unit IV**, the most recent A-1 ridge--wider and higher than the rest of the ridges. The modern beach is fairly broad, 30 m wide, and has a pronounced concave seaward slope.

The horizontal stratigraphy of Choris A, then, reveals wider ridges in two units: that of II and IV, with the Unit IV ridge much higher than any other ridges. The horizontal stratigraphy of Choris resembles that of Espenberg where four depositional units were defined on the basis of topography, dating, sedimentology and archaeology (Mason 1987a, 1987b and this volume, Ch. 2). At Espenberg, Unit I dates from 4000-3300 BP, contains low ridges; Unit II is a comparatively broad, dune/ blowout ridge dating before Choris and Norton culture times 3300-2000 BP; Unit III consists of a rapid progradational phase of low ridges dating between 2000-1200 BP, and the most recent Unit IV possesses higher dune and blowout ridges dating from 1200 to the present. Twenty laterally continuous ridges (with over 30 fragments) were deposited at Espenberg during the last 4000 years. The deposition of only nine ridges at Choris implies that only very exceptional storm events constructed ridges there. Each Choris ridge represents a series of storm events with material added until storms are no longer able to overtop it. Lower energy storms may cannibalize and re-distribute seaward earlier ridge deposits. As at Espenberg, the configuration of Choris ridges contains a storm history which reflects differences in wave energy and storm-induced sea level (Mason 1987b, this volume, Chs. 2 and 5).

Southeast Choris: Complex B

Located within a former cove in the southeastern portion of the Choris Peninsula, the B complex is the smallest of the three sediment packages (Fig. 4.1). The B ridges differ considerably from other Choris ridge complexes in terms of shape and internal relationships (Fig. 4.7). The B ridges are short and grade into one another. The complex is building from the southwest, as observed from the presence of numerous offshore bars about 200-300 m southwest of the complex. The modern beach is also widest on the southwest aspect. In the youngest vegetated unit ridges are oriented parallel to the coast. Sedimentologically, the B ridges are primarily pea gravels and small cobbles, but the oldest ridge within the complex, at the base of the cliffs, is capped by 20-30 cm of fine sand. Localized sand deposits are also observable on the berm of the modern beach and in places on the middle ridge.

Three different depositional units are distinguishable on infrared imagery, on the basis of vegetational differences (Fig. 4.7). The orientation of ridges shifts considerably between the units: the middle unit lies oblique to the coast while the oldest unit is closely parallels the bluff.

Only three archaeological sites were noted in my brief survey of the B complex, all near the margin of the bluff. All three sites are depressions--two probably former houses and the third a cache. Metal nails were noted in timbers used for construction on one house on one of the middle ridges. A metal nail was also noted in a test excavation into a 5 m long oval depression on the oldest ridge. Thus, no prehistoric sites useful in dating were found on the B complex. No firm correlations with either the other Choris complexes or with Espenberg can be made at this time.

East Choris: Complex C

The eastern Choris C complex (Fig. 4.7) forms a complement to the geomorphic setting of the western A complex (Fig. 4.1). Situated within a former embayment on the eastern shore of the peninsula, the C complex trends northwest/southeast for about 1.5 km along Eschscholtz Bay (Fig. 4.7). However, the complex shifts from a due north/south trend in its upper portion to a pronounced southeastern orientation in the lower, southern portion. The disparity in orientation is matched by differences in ridge accretion. While the northern portion of the C complex is composed of a continuous succession of linear ridges, the southern portion has an estuarine reentrant circumscribed by recurved ridges. The differences in ridge configuration are traceable to the influence of a small stream as it encounters the ridge complex near its midsection. Though the 1m wide stream is now underfit and is incised through the

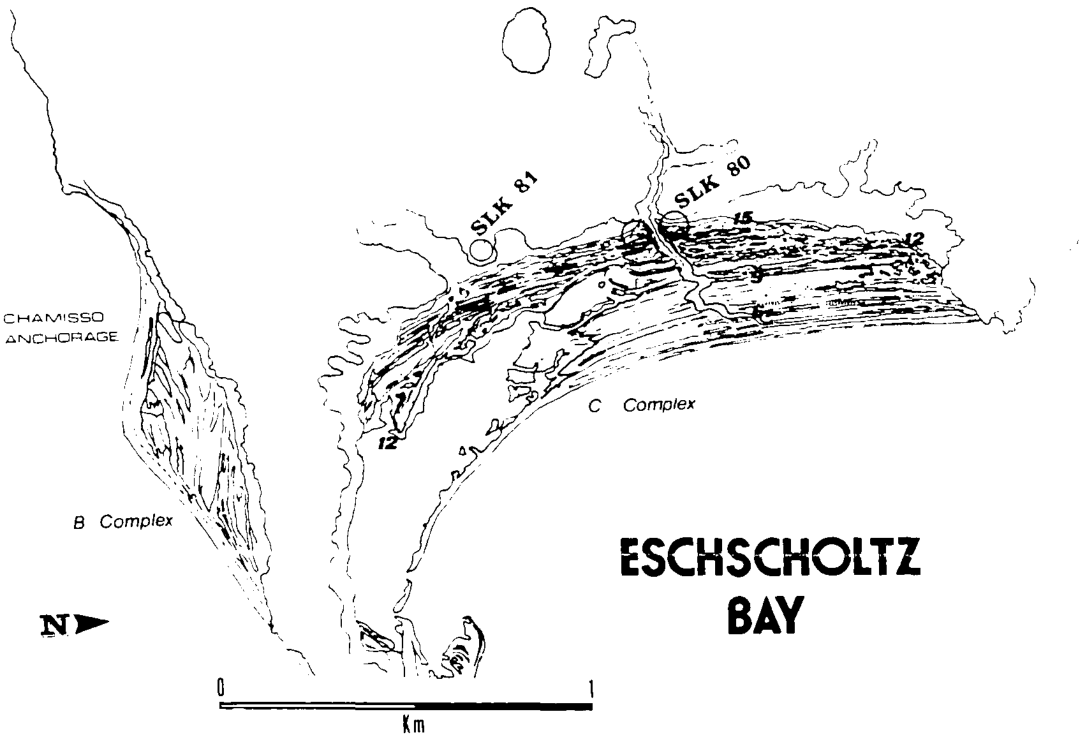

Fig. 4.7. Map of Choris B and C complexes. The Choris B complex, in southeast Choris Peninsula, lacks any archaeological sites older than the late prehistoric. The Choris C complex built as longshore transport delivered gravel and sand from the north. A small tributary deflected the ridge building process, producing an estuary. LateChoris/ early Norton artifacts occur on the C-15 ridge date ca. 3000-2000 yrs old.

bedrock bluff, at some point in time, its discharge must have been far greater. Hence, the creek contributed to the modification of longshore transport during the deposition of the earlier ridges at the C complex. Comparatively recently, ridges added from the north have isolated the estuary from Eschscholtz Bay (Fig. 4.7), as the creek shifted to the northeast because of the infilling of its former channel. Based on the recurved characteristics of ridges within the estuary and the nature of the ridge isolating the estuary from the bay, the dominant direction of transport in the C complex was northwest to southeast.

Fifteen principal ridge/ridge fragments are discernible in the Choris C complex. In elevation, all of the C ridges are less than 2 m above MSL. Ridges rise, generally, less than 0.8 m above the surrounding swales and the middle ridges (C-3,C-12, C-13) are 1.5 m above MSL. In profile, the C complex is dish shaped, with the middle ridges, C4 to C11 within a central lower basin with higher ridges at both extreme seaward and landward edges of the complex. Four swales are wider than others: between C2/3, C3/4, C8/9, and C11/12 and swale width decreases seaward (to the east) about 30 m between the older ridges (C8/9) and 10 m between the youngest (C2/3; C3/4) ridges The Choris C complex ridges are composed of gravel, pea size to small cobbles, but the oldest ridges are overlain by over 60 cm of coarse and medium sand. Sand is an appreciable constituent of the modern beach, although not on or near the surface of intervening ridges. The sand cap on the oldest C-15 ridge is due to the increased transport distances of individual saltating sand grains transported across over a gravel surface, documented by Bagnold (1954:73). Hence, sand may be eroded from all the younger ridges and is preferentially deposited on the oldest ridge at the base of the bluff. Overbluff dunes occur in isolated areas above the beach ridge complex.

The vegetation cover of the ridges reflects the sedimentary differences. Crowberry and other shrubs are common only on the most landward, oldest sand-covered ridges. The younger ridges are largely unvegetated, with lyme grass growing in protected swales. Lyme grass also increases in density toward the northern limits of the complex. Such differences in vegetation probably reflect groundwater entry and water retention properties of the ridges.

In the horizontal direction, the C complex at least two and possibly three different depositional units, based on vegetation, topographic and sedimentological differences. The oldest **Unit I**, composed of the C-15 to C-12 ridges, is distinguished by a stable groundcover of crowberry or lyme grass with ridges recurved landward toward the head of the small creek in the middle of the C complex. The middle **Unit II** is generally low-lying and unvegetated, with swales wider than the low ridges (C-11 to C-4). The most recent **Unit III** contains only three ridges, all largely unvegetated.

Archaeological Sites within/near the Choris C Complex:

Two archaeological localities were encountered during reconnaissance of the C complex: one on the oldest beach ridges and the other on a small sand knob about 7 m above the oldest ridge. Artifacts on the surface of the C-15 ridge (from SLK-081) included a side blade fragment and an intact projectile point with a straight base (Fig. 4.4). The two pieces fall within the general range of late Choris or early Norton (R. Gal, 1987; E. J. Dixon, 1987; personal communications).

A limited survey of the upland areas of Choris Peninsula by Giddings in the 1950's reported isolated traces of the older Arctic Small Tool tradition (ASTt) artifacts at an unspecified cliff location above the southeast cape of the peninsula. In my survey of the Choris C complex, a similar site (SLK-082) was discovered in a blowout within an over bluff dune, 7m above the southwest margin of the oldest ridge, C-15. A serrated blade fragment and other microliths provided an indication of an late ASTt occupation; I also found a square test pit, suggesting that Giddings or another archaeologist had visited the site.

Dating the History of the C Complex

The sole point of reference to estimate the depositional history of the Choris C complex derives from the archaeological sites on or above the C-15 ridge. The late ASTt artifacts imply that sedimentation started after 4000-3500 BP, while artifacts of late Choris or early Norton culture(s) places an upper limiting age 3000-2200 BP for the C-15 ridge, Unit I in the C complex. The younger ridges in Unit II at Choris C are low in elevation and separated by wide swales, resembling similar rapid progradational facies at Espenberg and Choris A. Hence, Unit II probably has a date range after 2000 until an unknown time in the last 700 to 1000 yrs. The last three ridges of Unit III in Choris C probably date to the last several hundred years.

Discussion: History of the Choris Peninsula Beach Ridge Complexes

The 100m knob of schistose bedrock comprising Choris Peninsula lies to the southeast of Cape Espenberg, across 85 km of open water in Kotzebue Sound. Gravel beach ridge plains formed within three former embayments of Choris Peninsula. The accumulation of sediment within each embayment reflects quite different influences: longshore currents from varying directions. The southwesterly Choris A complex built as north-westerly currents led to longshore transport from north to south (Fig. 4.1). Southerly winds led to the construction of the B complex, east of Pt. Garnett. On the east shore of Choris Peninsula, the C complex resulted as northeasterly winds crossed Eschscholtz Bay and produced sediment transport southeastward (Fig. 4.1).

Temporally, I suggest that both the A and C ridge complexes represent three depositional phases: (a) an older stable ridge in the earliest portion of the record, dating from 3000-2000 BP; (b) a progradational phase after 2200 BP and (c) higher ridge amalgam composed of the summation of storm events over the last several hundred years. At present, no firm temporal guideposts exist to establish the later history of the Choris complexes.

The sequence of nine beach ridges on the westernmost Choris A complex parallels the horizontal stratigraphy of Espenberg, both in plan and in relative height (Mason 1987b, this volume, Ch. 2). As at Espenberg, four depositional events may be traced within the west Choris A complex, with wider, higher ridges occurring only at two locations. Unit I includes only a single ridge at the base of the bluff. Unit II consists of a single comparatively wide ridge well- dated by archaeological remains at 3-2 kyrs. Unit III defines six, narrow ridges separated by wide swales. Unit IV is the most seaward ridge and is the most massive of the Choris ridges, about 90 m wide and 4.0 m above MSL.

As at Espenberg, higher ridges correlated with periods of increased storminess occur in only two periods: 3-2 kyr and between (estimated) 1 kyr and the present. Between 2-1 kyr, the rate of gravel ridge accretion at Choris increased in actual horizontal distance but with lower ridges, implying less intense storms in this period, as at Espenberg. During comparatively recent times--probably the last 500 years--a single ridge has formed. Though undated radiometrically, the modern ridge is the widest and highest (up to 4 m above MSL) of all Choris ridges and contains only late prehistoric to modern settlements. Since gravel ridges may be assumed to respond only to storm events, it may be argued that storminess has increased at a time after 2000 BP--and this event must be correlated with the most recent unit IV at Espenberg. The alignment of the Choris A complex to the west allows the impact of only a limited number of intense storms--from the west-northwest (Figure 4.1). This limited fetch window allows the reconstruction of most prevalent storm tracks during the periods of heightened storminess, 3.3-2 kyr and 1.2 kyr to the present.

On the eastern aspect of Choris Peninsula, fifteen low gravel ridges have added (Choris C complex), due to deposition within the comparatively small Eschscholtz Bay which has only about 50 km of maximum fetch from the east. Eolian deposits are above the oldest ridges and contain ASTt related artifacts probably about 3500 years old. Otherwise, the eastern Choris ridges are divisible into three depositional units: the oldest Unit I is capped by over 50 cm of sand, completely vegetated by crowberry and grasses, contains diagnostic Choris or early Norton artifacts and probably dates to 3000-2000 BP. The undated Choris C complex Units II and III are unvegetated and are distinguished by increasing differences in swale width.

The gravel ridges at Choris respond solely to the onslaught of major storms. By comparing their record to that of the "ever-changing" sands at Espenberg, we gain a fuller under-standing of late Holocene storm conditions. The depositional sequences at both complexes are in accord--heightened storminess occurs at 3-2 kyr and from 1.2 kyr to the present. Hence, the beach ridge complexes of Kotzebue Sound provide a variable proxy record of storm periodicity during the late Holocene, as I describe in Chapter 5.

Chapter 5

Conclusions: Regional Integration

Cross-Correlating Northwest Alaska Beach Ridges: A Proxy Climate Record for the Late Holocene.

Introduction

The shores of Northwest Alaska reveal a complex horizontal stratigraphy of beach ridges formed in response to the climatic conditions of the late Holocene. The shoreface on such exposed, sediment-rich coasts is particularly sensitive to changes in short-term weather patterns (Davis 1972, Davis and Fox 1975). Patterns of long-term progradation provide a proxy record of older climatic events. Progradational regimes prevail under microtidal conditions, a slow rate of relative sea level fluctuation and with a plentiful sediment supply (Curray 1964, Hayes 1979). If all these conditions are satisfied, complex sequences of beach ridges and/or coastal dunes are produced (Curray et al. 1969, Kraft and Chrzastowski 1985).

Studies of prograding coastal systems have yielded detailed records of alluvial and deltaic shifts; for example, in Mexico (Curray et al. 1969), Louisiana (Gould and McFarlan 1959), Georgia (DePratter and Howard 1977) and China (Liu and Walker 1989). Fluctuations in Peruvian beach ridge swale widths may be linked to shifts in the El Niño sea surface anomaly during the last 5000 years (Sandweiss 1986). Australian workers find a complex relationship between arid conditions in the interior and storm frequency on the coast (Beaton 1985, Chappell and Grindrod 1984) or variations in the position of dominant "cyclonicity" or frontal systems (Thom 1978).

Pioneering researchers in Alaska recognized that erosional disconformities could be used to infer shifts in paleo-wind direction (Moore and Giddings 1961, Moore 1966). Although ridge position (ie. landward=more ancient) was easily used as an archaeological survey strategy (Giddings and Anderson 1986), little research had focused on the forcing mechanisms underlying the formation of beach ridge complexes in particular locations Giddings (1967:18ff). To this end, I describe the horizontal chronostratigraphy and correlations among beach ridge complexes from western Alaska. In brief, conditions of heightened storminess prevailed from before 3000 to 2000 BP and from 1200 BP to the last one or two hundred years. Less frequent and less intense storms conditions characterize the millennium between 2000-1000 BP.

Distribution of Beach Ridges in western Alaska

Beach ridge and chenier ridge systems are common along the Bering and Chukchi Sea shores of western and northwestern Alaska, from the Yukon Delta to Point Hope (Fig. 2.1). Four principal prograding systems occur along the shores of the northern Bering Sea.[1] Chenier ridges flank the modern Yukon Delta from Hooper Bay to Stebbins in Norton Sound (Hoare and Condon 1966, 1968; Dupre 1984, written comm.). A series of gravel and sand ridges generated a 8 km long spit east of Cape Nome, enclosing Safety Sound (Bockstoce 1979). The recurved sand and gravel spit of Point Spencer (Black 1946) formed at the mouth of Port Clarence on southwestern Seward Peninsula. On St. Lawrence Island beach ridges produced a gravel foreland at North Cape near Gambell (Collins 1937).

North of Bering Strait, along the southeast shore of the Chukchi Sea and its rhomboidal embayment, Kotzebue Sound, beach ridge complexes occur at critical shifts in coastal orientation (Fig. 2.1). The seven major beach ridge complexes are situated at: Cape Prince of Wales, Cape Espenberg, Choris Peninsula, Kotzebue, Sisualik, Cape Krusenstern and Point Hope (Fig. 2.1). My principal focus is the ridge complexes of

[1] Several other unsurveyed complexes could be added: (1) at Unalakleet and Shaktoolik on the east shores of Norton Sound in the Bering Sea (cf. Riehle et al. 1981); (2) at the mouth of the Inmachuk River near Deering in southern Kotzebue Sound

Kotzebue Sound itself and limited attention is given to three of the Bering Sea complexes: the Yukon cheniers, Safety Sound and Gambell.

**Studies of Alaska Beach Ridges:
the Problem of Cross-Correlation**

The onset of beach ridge studies in Alaska dates from the archaeological excavations and relative age estimates of Henry Collins (1937) in the 1930's at Gambell on St. Lawrence Island (Mason and Ludwig in press, this volume, Appendix). The extensive surveys of J. Louis Giddings (Giddings and Anderson 1986) in 1956-1962 led to "beach ridge archaeology" (Giddings 1967). Beach ridge archaeology was conceived as a relative dating method and a site survey strategy (Giddings 1967:16ff, Giddings and Anderson 1986:6, Mason this volume, Ch.1). Although Giddings surveyed, tested and dated many of the beach ridge complexes in northwest Alaska, he never attempted to cross-correlate deposits from different complexes.

The breadth and duration of research varies widely from one beach ridge complex to another (Giddings and Anderson 1986). Cape Krusenstern was extensively examined by J.L. Giddings from 1958-1962, resulting in a rudimentary chronology (Table II-1) based on radiocarbon dates (n=33) from only seven of the 114 ridge segments (Mason and Ludwig in press, this volume, Appendix). Giddings surveyed Cape Espenberg in 1958 and very briefly re-visited it in 1960. He excavated and surveyed at Choris in 1956, 1958 and 1960; examined the youngest portion of Sisualik spit in 1958 and the northeastern extreme portion of the complex near Wales in 1959. Larsen and Rainey (1948) investigated archaeological sites on the oldest Pt. Hope ridges in 1939-1941. Limited sedimentological studies were undertaken at the Pt. Hope by Sharma (1972) in concert with further archaeological excavations of late prehistoric Tigara mound by Hosley (1972). Black (1946) mapped and described the Pt. Spencer spit; Larsen (1979/80) briefly examined archaeological remains at the Pt. Spencer spit. In the late 1960's Bockstoce (1979) tested numerous archaeological features on the "Old Beach" portion of the Cape Nome/Safety Sound ridges. The National Park Service (NPS) surveyed portions of the Cape Espenberg spit and the Shishmaref barrier islands in 1986 (Schaaf 1988a, 1988b) and conducted limited excavations at six sites in 1988 and 1989 (Harritt 1989, 1990). Backhoe trenches were placed across several gravel ridges at Kotzebue by the Alaska Dept. of Transportation (Brian Gannon 1990, pers. comm.). In conjunction with the NPS, I conducted geoarchaeological research at Cape Espenberg from 1986 to 1989 and at Choris Peninsula in 1987, through the auspices of the Alaska Quaternary Center and University of Alaska Museum.

The pioneers of beach ridge archaeology asked how and why ridge complexes formed. My research seeks to answer that question. To examine beach ridge history and correlations, it is necessary to consider the prevailing regional meteorology, the wave climate and the history of sea level fluctuations.

Wave Climate and Meteorology of the Chukchi Sea

The Chukchi Sea is an embayment of the Arctic Ocean bounded by the shores of northwest Alaska (U.S.A.) and northeast Siberia (U.S.S.R.). The sea lies north of Bering Strait (65° N. lat.), its southern outlet, and extends to the fluctuating summer limit of Arctic pack ice at about 71° to 75° N. lat. (Fig. 2.1). The Chukchi Sea is microtidal (tidal range probably less than one meter). At Shishmaref, on the south shore of the Chukchi Sea, the tides show an estimated range of up to 0.76 m with the highest tidal debris at only 0.975 m above mean sea level MSL[2] (Peratrovich and Nottingham 1982:7). At Cape Espenberg drift debris is found at elevations up to 2.25 m above mean sea level (MSL). Sea levels may be elevated as much as 40 cm during the passage of low pressure systems (Hunkins 1965). Ice covers the entire Chukchi Sea during the winter months, leaving only the annually variable 4-5 month period from June to October subject to open water oceanic processes (LaBelle et al. 1983).

The trend of surrounding landmasses orients the Chukchi Sea north-west/southeast in relation to the direction of maximum wind fetch--the distance available to wind stress. Wind fetch is an important variable for shore processes since potential wave height increases with fetch (Komar 1976). As seen in Table I, fetch distances vary considerably across the Chukchi Sea; from only about 185 km west to east at Shishmaref, up to 1125 km from the Northwest or North to South during conditions of maximum open water from Wrangel Island to Shishmaref. For the

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[2] For this study Mean Sea Level (MSL) refers to mean low water because tidal fluctuations are so insignficant (±0.75 m). Field observations were made during summers of 1986-88. No gauge data is available for this region.

northeast Bering Sea, fetch distances can be well over 1000 km, if winds blow from its southwest margin near the Komandorski Islands.

Ultimately, the transit of weather systems governs the regional wave climate (Fox and Davis 1972). The limited instrument record (40 yrs) indicates that major storms cross the Bering Sea and enter the Chukchi Sea from the southwest by way of the Bering Strait. High intensity storms are common during autumn, especially in September and October (Wise et al. 1981). The path and speed of an individual storm system vary latitudinally and longitudinally (Kowalik 1984) as a result, waves are generated from various quadrants of the compass. In the initial phase of storm entry, strong winds may issue from the southwest Bering Sea (with fetch distances over 1000 km) and produce high waves directed at the northern shore of Kotzebue Sound at Cape Krusenstern and farther north at Point Hope. Subsequently, after a storm moves into the northern or central Chukchi Sea, the south shore of the Chukchi Sea may be affected by high waves. In 1973-74 southerly winds associated with several fall storms led to storm surge conditions in both Norton and Kotzebue Sounds (Fathauer 1975). Water level rose along the northern Seward Peninsula coast and waves up to 5 m in height were reported at Shishmaref (Wise et al. 1981). To assess potential storm affects at Shishmaref, Peratrovich and Nottingham (1982) considered only the 125 km of available from due west. Those researchers concluded that very minor storm surges, < 1 m above MSL, had a likely recurrence interval of 50 yrs. J.W. Jordan (n.d.) estimates larger surges , 2-3 m above MSL , occur every 10 yrs.

West, north or northwest winds prevail across the Chukchi Sea during the open water period, June to October (La Belle et al. 1983). During periods dominated by high pressure or lacking high intensity storms, west or northwest winds of only $\leq$4.47 m/sec produce a northeast setting longshore current. This current regime has prevailed during the last 80 yrs, according to oldest informants at Shishmaref (Gideon Barr in J.W. Jordan, unpublished notes, 1988).

Currents

Deposition along the coast is influenced by the identity, strength and speed of water masses and currents. The principal water mass affecting the west Alaska coast is the Alaskan Coastal Water which enters the Bering Sea from the Gulf of Alaska. Alaska

Coastal Water flows along the coast to the Yukon Delta and follows the 20 m isobath north to the Bering Strait. Then, the Alaska water mass trends north about 60-80 km and either continues toward Pt. Hope or diverges northeast into Kotzebue Sound--at an annually variable amount. The swiftest upper level flows of 150 cm sec^{-1} are encountered in the eastern channel of Bering Strait, speeds of about 50 cm sec^{-1} occur in the central Chukchi Sea,with a marked deceleration to 15-20 cm sec^{-1} at the entrance to Kotzebue Sound (Coachman et al. 1975:140). Bottom water can attain speeds of up to 30-35 cm sec^{-1} along the north coast of Seward Peninsula, fast enough to transport fine sand and silt (McManus et al. 1969).

Since longshore sediment movement is tied to the effects of onshore winds (Komar 1976, Moore 1966), Moore and Giddings (1961) linked the development of beach ridge complexes to variations in prevailing storm wind direction throughout the late Holocene. Progadation can occur in conjunction with rising sea levels only if the supply of sediment keeps pace (Curray 1964), so the regional trend of sea level rise is important.

Sea Level History in the Chukchi and Bering Seas

The Chukchi Sea, less than 80 m deep, was subaerially exposed as part of the Beringian subcontinent during the late Pleistocene, due to eustatic effects. Norton Sound is even shallower, about 20-30 m deep. The Holocene transgression across the Chukchi shelf began with the flooding of the Chukchi valley in the north about 17 kyr which created a narrow estuary. Sea level rose at an approximate rate of 6 m/1000 years, reaching about -30 m at 12 kyr BP. By this time, Shpanberg, Anadyr and Bering Straits were flooded and nearly modern oceanic circulation was established (McManus and Creager 1984). After 12 kyr BP, sea level rise slowed considerably, asymptotically approaching near modern sea levels around 5000 years ago.

The formation of beach ridges in Kotzebue Sound, dated after 4000 BP, provides a limiting date on the establishment of near modern sea levels, as suggested by Moore (1961) and Hopkins (1967, 1973). Rapid eustatic sea level rise during the early Holocene (ca. 10-6 kyr) probably precludes the occurrence of terrestrial deposits before the comparative stabilization of sea levels after 4000 BP in the Chukchi Sea. Early Holocene shoreface deposits may be preserved as degraded barriers or shoreface retreat massifs (sensu Swift 1975).

Short-term eustatic sea level fluctuations may have produced higher ridges from 2000 BP to 900 BP at Point Hope, Cape Krusenstern (Moore 1960) and Pt. Barrow (Hume 1965, Brown and Sellmann 1966). However, sea level may have been only temporarily elevated due to low barometric pressure associated with storms which resulted in the emplacement of high gravel ridges (Mason this volume, Ch. 2). In any case, since beach ridge complexes have prograded at nearly all the critical headlands of the Chukchi Sea, I assume that sea level has varied no more than 1-2 meters during the late Holocene, ie., 2500 BP to the present. As further evidence of sea level stability, there is no evidence of tectonic changes (ie. uplift or subsidence) at the margins or beneath Kotzebue Sound during the Holocene, as described below.

Tectonic Setting

Kotzebue Sound and Seward Peninsula lie within a moderately active seismogenic province connected to the Brooks Range within a zone "characterized by a relatively thin crust, scattered Quaternary volcanism [and a] relatively high heat flow....[in a] regime of extensional tectonics" (Thenhaus et al. 1982:7). The northern Seward Peninsula coastal plain and Kotzebue Sound are the surface expression of a subsiding basin of Cenozoic sediments several thousand meters thick. The sediments are crosscut by several east/west faults just south of Cape Espenberg, which are splays of the Kobuk system (Hopkins 1988). Little vertical motion has been observed during the Holocene, the time scale of this study. To the north of Espenberg, high resolution reflection studies show an absence of Holocene activity on faults covered by transgressive marine deposits on the submarine Kotzebue Ridge, in the Chukchi Sea north of Seward Peninsula (Eittreim et al. 1977). In light of this quiescence, the shores of Kotzebue Sound may be regarded as tectonically stable for the period of this study.

Source Materials: Geology of the Chukchi Sea and its shores

To understand the formation of beach ridge complexes in western Alaska, it is necessary to consider the sediments available for transport and their susceptibility to deposition. Both terrestrial and offshore shelf sediment sources are involved. The north and south coasts of Kotzebue Sound differ considerably geologically and topographically. The portion of the south shore, formed by the northwest Seward Peninsula, is fringed by sandy barrier islands and accretionary sand ridge plains. The southernmost coast near Deering and the entire north coast of Kotzebue Sound are dominated by bedrock cliffs and gravel ridge systems. The eastern shore of Kotzebue Sound is composed either of bedrock knobs such as found on Choris Peninsula or the glaciomarine diamictons of Baldwin Peninsula.

The southeast shore of the Chukchi Sea is defined by the northwest Seward Peninsula, a low-lying, silty sand mantled, permafrost-dominated plain subject to several cycles of thaw lake formation during the Pleistocene and Holocene (Sainsbury 1967, Hopkins 1988, Hopkins and Kidd 1988). Little sediment enters the Chukchi Sea from the small rivers draining the north slope of the Seward Peninsula due to low sediment concentrations and discharges (Creager and McManus 1966).

Several beach ridge plains lie downdrift from Mesozoic or Precambrian bedrock knobs. For example, as Safety Sound lies downdrft from Cape Nome, as the Wales complex is from Cape Prince of Wales and as Pt. Spencer is downdrift from Cape Douglas. In other cases, eroding, unlithified bluffs are supplying sediment downdrift to construct beach ridges, as at Cape Espenberg (Mason this volume, Ch. 2) and Choris Peninsula (Mason this volume, Ch. 4). Interior Seward Peninsula tephra sands in alluvium (Hopkins 1988) and eroding bluffs near the Kitluk River mouth contribute sand to the formation of Cape Espenberg spit (Fig. 2.2). These tephra sands are not found on the Shishmaref Inlet barrier islands, to the southwest, and record the direction of prevailing longshore drift to the northeast.

The floor of the southern Chukchi Sea is covered by medium to fine sand, silt, and clay (Creager and McManus 1966, McManus et al. 1969, McManus et al. 1977). The finer silts and clays derive either from the Noatak and Kobuk Rivers or the Yukon River (Naidu and Mowatt 1983). A massive sand shoal extends east and northeast of Cape Prince of Wales, at the Bering Strait in the Chukchi Sea. The Wales shoal was probably deposited during the early Holocene (before 5 kyr BP) by northward currents through the Bering Strait (McManus et al. 1969). The large reservoir of offshore sands in shallow waters (<20m) off the Seward Peninsula coast leads to energy dissipative, nearly flat beach profiles (Wright et al. 1979) common on sandy coasts. Such flat beaches damp the energy of storm waves but allow greater landward penetration of these waves (Short and Hesp 1982, Leatherman and Zaremba 1987).The development of foredunes, washover deposits and transgressive dunes is favored within sandy materials (Short and Hesp 1982, Ritchie and Penland 1988). Thus, this possible translation of sediments onshore confounds the simple correspondence between linear ridges and former shore position.

The northern shore of Kotzebue Sound consists of uplifted Paleozoic limestones interbedded with shale, chert and dolomite which form hills over 500 m in elevation (Campbell 1966, Selkregg 1975, Mayfield et al. 1983). Other rocks include: Mesozoic mudstones interlain with siltstones and sandstones. These lithologies form gravel on the north shore beaches and are subject to longshore transport as materials are eroded from cliffs and alluvial fans, though some offshore sediments are moved onshore (Hopkins 1986). Cape Thompson, 45 km southeast of Point Hope, marks a break in direction of littoral drift: sediment moves either southeast or northwest from the headland (Moore 1966).

Clasts on Choris Peninsula complexes are cobble, granule or coarse sand; of predominantly chert, quartzite or schist (Mason 1987, field data). Choris Peninsula is a low bedrock knob connected by beach sediments to Baldwin Peninsula. The southern portion of the Peninsula consists of middle Paleozoic mica schist (Patton and Miller 1968). Bottom sediments offshore are silts and fine sand (Creager and McManus 1966) which forms a significant component of some of the ridges (Mason 1987, unpublished data). Hence, most of the beach clasts are eroded from from bluffs north of the bedrock knobs. Erosion and longshore re-transport southward of glacial outwash deposits forming the Baldwin Peninsula to the north of Choris probably accounts for some of the exotic material (Mason this volume , Ch. 4).

Methods

The sample of beach ridge complexes discussed here includes eight: six from the Chukchi Sea and two from the Bering Sea (Fig. 5.1). The two most thoroughly studied complexes lie opposite one another on Kotzebue Sound: Cape Espenberg (E) and Cape Krusenstern (K). The other Kotzebue Sound complexes of Choris Peninsula (C) and Sisualik are less well studied. Two complexes are outside of Kotzebue Sound: Point Hope (PH), 150 km northwest of Krusenstern, and Wales, near Bering Strait. For the Bering Sea, cross-correlations are tentatively proposed, using the Safety Sound and

Gambell complexes.

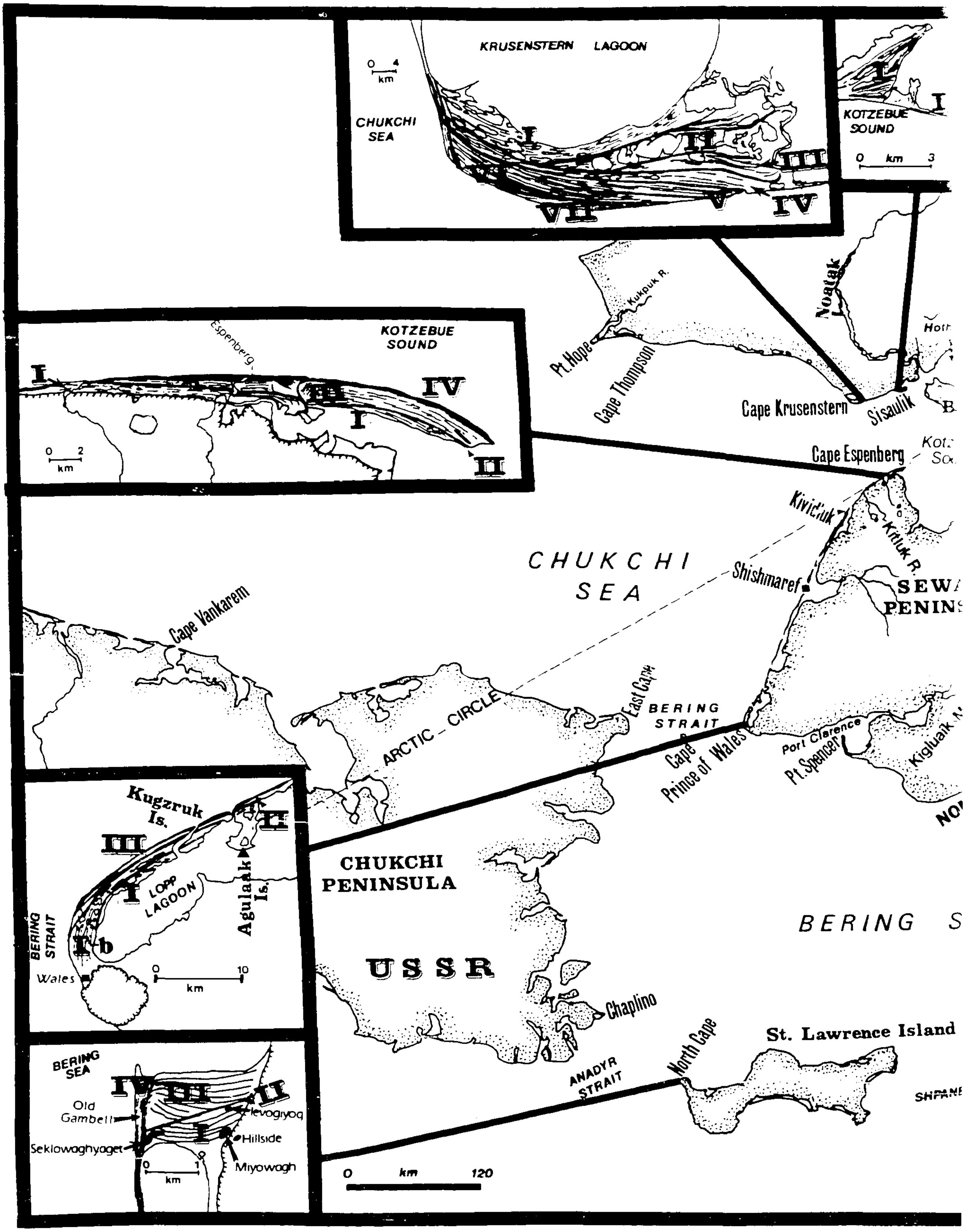
Ridge designations follow the conventions of archaeologist Giddings (1963) who chose to number ridges sequentially higher landward from the modern beach (1 is the youngest). Chronostratigraphic units are denoted by Roman numeral (I, II, III....) and follow geological practice with the lowest number (I) being the oldest depositional unit.

The correlation of Alaska beach ridges is based on several lines of evidence. Foremost is the standard use of radiocarbon samples derived from both archaeological and geological contexts. My delineation of depositional units was based largely on the interpretation of aerial photos, using false color or near visual infrared imagery obtained by low-flying aircraft. Aerial photos used included the (a) widely available National Ocean Survey (NOS) imagery produced at a scale of 1:35,000; (b) NASA imagery at 1:62,500 scale; and (c) special National Park Service (Alaska Regional Office, Anchorage) commissioned overflight photographed at 1:8,000. The first two sets of photos are available through the Geodata Center of the Geophysical Institute, UAF.

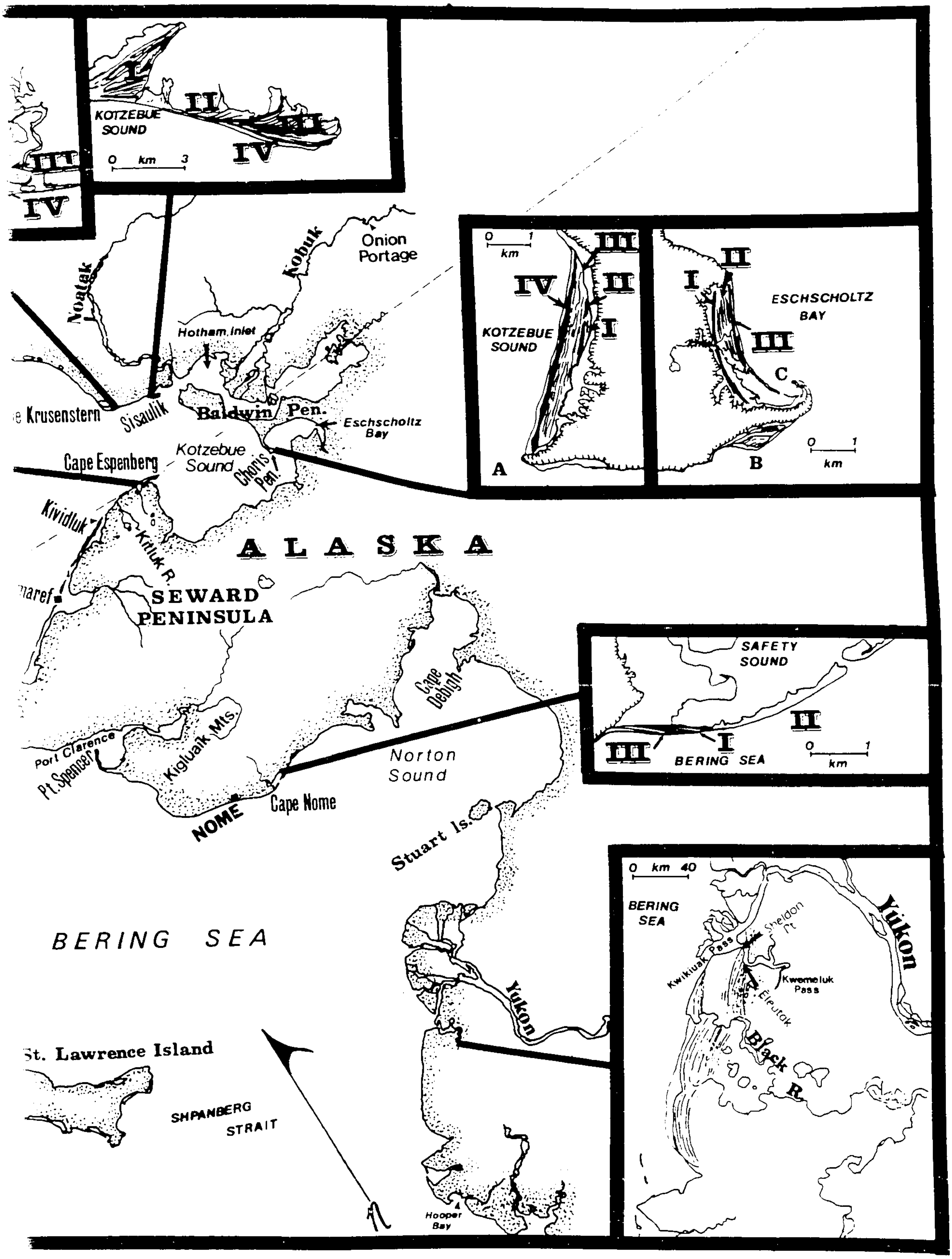
Criteria used in the delineation of depositional units included: differences in vegetation cover, moisture content of the ground surface, morphological differences in ridges, lake configuration and the development of distinctive geomorphic features such as frost cracks, palsas (ice-cored hummocks) and lakes. The entire study locale lies within the region of discontinuous permafrost (Péwé 1975) and the patterns of multi-seasonal continued freezing of surficial sediments permits the growth of polygonal features. The trellis-like patterns due to permafrost induced cracks increase with moisture content, age and grain size. Ponds and lakes may also be influenced by biogenic and/or cryogenic processes. These include the growth and degradation of peat in response to changing moisture regimes which is governed in part by the impeded drainage resulting from the development of palsas and peat ridges.

Photo-interpretations were personally ground-truthed at Cape Espenberg and Choris; and benefited from discussions with colleagues for several of the others. At Espenberg and Choris several additional lines of evidence were used in distinguishing depositional units and will be further described below. Sedimentological samples and stratigraphic descriptions were conducted in a transect of the two beach ridge systems. The resulting data includes altitudinal and slope measurements, granulometric statistics and pedologic characteristics (Mason 1987, and unpublished data). These data are presented elsewhere (Mason this volume, Ch. 2, 3 and 4).

Fig. 5.1. Map of Chukchi and Bering Sea beach and chenier ridges (main map). Depositional units for individual complexes: (a) Gambell; (b) Wales; (c) Cape Espenberg; (d) Cape Krusenstern; (e) Sisualik; (f) Choris Peninsula, west and east; g) Safety Sound/ Cape Nome; (h) Yukon Delta. Depositional units given in Roman numerals, see text. Radiocarbon dating constraints listed in Table II.



KRUSENSTERN LAGOON
CHUKCHI SEA
KOTZEBUE SOUND
KOTZEBUE SOUND
Espenberg
Kukpuk R.
Noatak
Pt. Hope
Cape Thompson
Cape Krusenstern
Sisaulik
Cape Espenberg
Kividluk
Kitluk R.
Shishmaref
CHUKCHI SEA
Cape Vankarem
ARCTIC CIRCLE
East Cape
BERING STRAIT
Cape Prince of Wales
Port Clarence
Pt. Spencer
Kugzruk Is.
LOPP LAGOON
Agulaak Is.
BERING STRAIT
Wales
CHUKCHI PENINSULA
USSR
BERING
Chaplino
North Cape
ANADYR STRAIT
St. Lawrence Island
BERING SEA
Old Gambell
Ievogiyoq
Hillside
Seklowaghyaget
Miyowagh
km
0 km 120


KOTZEBUE SOUND
0 km 3
I
II
III
IV
Noatak
Kobuk
Onion Portage
Hotham Inlet
Krusenstern
Sisaulik
Baldwin Pen.
Eschscholtz Bay
Cape Espenberg
Kotzebue Sound
Choris Pen.
Kividluk
Kitluk R.
ALASKA
SEWARD PENINSULA
Cape Deubigh
Port Clarence
Pt. Spencer
Kigluaik Mts.
NOME
Cape Nome
Norton Sound
Stuart Is.
BERING SEA
Yukon
St. Lawrence Island
SHPANBERG STRAIT
Hooper Bay
0 1 km
KOTZEBUE SOUND
A
ESCHSCHOLTZ BAY
C
B
SAFETY SOUND
BERING SEA
0 km 40
Kwikluak Pass
Kwemeluk Pass
Black R.

The regional cultural chronology plays a substantial role in the dating and correlation of sedimentary deposits in Kotzebue Sound. Summarized in Table III, the cultural sequence extends over 4000 years and probably represents the occupation of coastal Alaska by the ancestors of Inupiat and Yup'ik (Eskimo) people (Anderson 1984, Giddings and Anderson 1986, Dumond 1987). Several diagnostic artifacts and house types provide critical time referents and have been used similar to index fossils. The earliest, pan-regional archaeological horizon dating to 4500-3500 BP is the Arctic Small Tool tradition (ASTt), marked by a distinctively flaked micro-lithic technology, the absence of ceramics, fire hearths and circular temporary shelters. After this initial occupation, more localized archaeological cultures are distinguished sequentially on the basis of temporal changes in: (a) decorative motifs on harpoon heads and ceramics, (b) the shape of houses from round/oval to rectangular subterranean and (c) in the proportion of lithic artifacts increasingly made on ground slate.

The Radiocarbon Sample

The correlation of depositional units at northwest Alaska beach ridges relies on 147 radiocarbon samples (Table II) collected predominantly (97.3%) from archaeological contexts. A total of 142 archaeological ^{14}C dates exists for the region north of the Yukon Delta, including 49 from St. Lawrence Island (Mason and Ludwig in press; this volume, Appendix), nine from Safety Sound (Bockstoce 1979), four from Lopp Lagoon (Giddings and Anderson 1986:30), 32 from Cape Espenberg (Schaaf 1988a, Harritt 1989, 1990), four from Choris (Giddings and Anderson 1986:30), 33 from Cape Krusenstern (Giddings and Anderson 1986:30, Gfeller et al. 1961) and 11 from Pt. Hope (Arnold and Libby 1952, Gal 1982, Larsen 1982, written communication). Dates from geological contexts (only 2.7%) include just five from Cape Espenberg (Mason and Jordan 1989).

The total body of 147 radiocarbon dates represents a diverse body of organic materials (Table IV). Nearly three quarters (112 of 147) were run either on charcoal (n=55, or 37.4 %), wood (n= 50, or 34.1%) or a mixture of the two materials (n=7, or 4.8%). A significant number derive from charred and cemented sea mammal remains (n=21, or 14.3 %). Other materials form a small percentage: bone and antler (n=6, or 4.1%), marine shell (n=2, or 1.4%), grass (n= 3, or 2%) or materials termed "skin" or "food" (n=3, or 2%) likely sea mammal in origin. Dates derived from remains of marine organisms are probably biased due to the long residence time of carbon in the oceans (Stuiver and Pearson 1986). Based on paired dates from non-marine and marine materials at St. Lawrence Island and Cape Krusenstern, Mason and Ludwig (in press, this volume, Appendix) estimate that a correction factor of about 400 yrs should be applied to west Alaska dates based on marine organisms. Dates on wood may be as much as 250-300 yrs too old due to the dating of long-lived tree samples (Taylor 1987) and the 35 yr residence time of driftwood deposited by occasional storm surges on the backbeach (Giddings 1941).

Part of the bias in material dated reflects the collection bias or limitations of preservation (Table IV). Wood figures so predominantly at Gambell (77%) due to the failure of 1930's researchers to collect charcoal in the pre-radiocarbon era and the concentration on the excavation of cemetery remains by later researchers. Similarly, the use of charcoal (84%) at Espenberg in preference to wood records the modern disfavor toward wood samples, (available as structural elements in younger aged houses at Espenberg) as well as the lack of wood in earlier occupations at Espenberg. At Krusenstern, little charcoal was observed in the oldest ridges and in many of the younger occupations.

Geographically, the date list presents several research-related trends (Table II). The largest single block of dates (n=49, or 33%) was obtained from the Gambell foreland in the Bering Sea, but controversy surrounds some of the samples (n=15), collected in the 1930's and run by the solid carbon method in the 1950's (Mason and Ludwig in press, this volume, Appendix). The Safety Sound complex east of Cape Nome has several dates from its gravel ridge portion (n=9, or 6.1% of the total). Otherwise, the date list is predominantly from Kotzebue Sound--88 of the total or nearly 60%. The two large Kotzebue Sound complexes, Cape Espenberg (n=37, or 25%) and Cape Krusenstern (n=33, or 23%), comprise nearly half of the total dates, with limited dates from three other complexes: Pt. Hope (n=11, or 7.5 %), Choris (n=4, 2.7%) and Wales (n=4, or 2.7%).

Not all time periods are reflected equally in the corpus of radiocarbon dates. Though all four depositional units at Espenberg are dated, 62% of these dates were obtained from the youngest unit. Only seven of the 114 Krusenstern ridge fragments are dated, with the early (and geologically crucial) enigmatic archaeological Old Whaling occupation disproportionately claiming 19 of the 33 (58%) dates. Similar temporal biases are observable at Pt. Hope, Choris and Wales where none of the more recent (less than 1000 years old) occupations are radiometrically dated. On Gambell, the bias in dating again favors the older occupations with no dates available from late prehistoric villages.

The Onset of Beach Ridge Deposition in Northwest Alaska

As sea levels stabilized in the late Holocene, sediments transported into the nearshore became susceptible to storage within prograding spits and ridge complexes. The onset of beach ridge accretion is dated in reference to superimposed archaeological cultures and to non-cultural stratigraphic markers such as tephras and dated paleosols. At 4000-3700 BP people of the micro-lithic Arctic Small Tool tradition (ASTt) (Table III) camped at Cape Krusenstern, Lopp Lagoon, northeast of Wales, Cape Espenberg and Safety Sound (Giddings 1964, 1967; Bockstoce 1979, Giddings and Anderson 1986, Schaaf 1988b). Dating of the Krusenstern ASTt occupation is tied to the Bands 4 and 5 in the well-dated, deeply stratified Onion Portage site, an alluvial site in the middle Kobuk River (Anderson 1988:48). Since ASTt remains occur on the K-100-104 and not the oldest K-114 beaches, Giddings (1961:161) reasoned "if the ridges...formed with the apparent periodicity of the last 40 ridges"--possibly an untenable assumption--then, the onset of beach ridge sedimentation at Krusenstern probably started at ca. 5000 BP.

At Cape Espenberg several ASTt-related occupations are recorded on the oldest ridges (Giddings and Anderson 1986, Schaaf 1988a, 1988b); one camp site attributed to ASTt peoples dates to 3570 ±100 BP (ß-19643) (Schaaf 1988b:281), while another dates to 3750 ±80 BP (ß-33758) (Harritt 1990). On Choris Peninsula, ASTt-related artifacts occur within overbluff dunes 7 m above the east shore and on 100 m high bluffs above the west shore. Both ASTt loci at Choris lie above the beach ridge complexes; but are undated radiometrically (Mason 1987b). At Safety Sound in Norton Sound, the micro-liths related to ASTt are also undated and were found within a gravel ridge later transgressed by storms (Bockstoce 1979).

Only the Cape Espenberg complex has purely geological evidence useful in estimating the beginning of beach ridge sedimentation: a tephra is contained within a buried paleosol on the oldest E-20 sand ridge. This thinly bedded (<1 cm) distal tephra is provisionally linked (R. Miyaoka 1988, written communication , analysis by J.

Riehle on-going) to the Aniakchak eruption, dating to ca. 4000-3400 BP (Miller and Smith 1987, Riehle et al. 1987). A date on a buried grass layer from the same (E-20) ridge yielded a date of 3700 ±90 BP (ß-23170) (Mason and J. W. Jordan 1989), provides an upper limiting age estimate of ca. 3880-3580 BP (using a two sigma range) for the formation of the ridge.

Controls over Beach Ridge Deposition: Sand versus Gravel

After 3500 BP the depositional history of the six principal complexes may be broadly correlated, bearing in mind that sand and gravel respond differently to storm wave climates (Shepard 1973:127, Wright et al. 1979, Orford and Carter 1982, Orford 1987). Gravel forms higher, steeper (up to 24° in the case of cobbles) energy reflective beaches, allowing waves with greater amplitude to break closer to the shore. The high-angled gravel beach forms a ramp and clasts are pushed up to the crest. Since only storms with the highest energies can drive clasts up the beachface, the gravel system is able to absorb numerous smaller storm events without producing a distinctly new ridge. The process of constructing a gravel ridge probably involves the cumulative effects of high magnitude storms. The amount of time involved in this process is well-documented at Safety Sound where the same ridge contains stratified archaeological materials of about 3500 yrs old and about 2400-2000 years old (Bockstoce 1979:19-39).

Energy dissipative, planar (slopes of only 1°-3° in fine or very fine sand, Shepard 1973:127), beach profiles are common in sandy sediments. Such flat beach faces damp the energy of storm waves but allow greater landward penetration of waves. The development of foredunes, washover deposits and transgressive dunes is favored within sandy materials. The translation of sand onshore confuses the simple correspondence between linear ridges and former shore position. Since gravel beach ridges involve wave action along, their position closely reflects paleo-shoreline position. By contrast, sand may be moved onland by the wind and sand ridge crests does not necessarily correlate with former shorelines.

The building of a dune superimposed on a beach ridge requires primarily that the location of the shoreline remain constant. That is, a net erosional state predominates in the foreshore, precluding the formation of multiple berm ridges but the occasional large storms translates sand into the backbeach, where sand-tolerant plants are favored and able to grow apace with high sand supplies (Mason this volume, Chs. 2 and 3).

A Kotzebue Sound Type Section: Cape Espenberg

At present, due to the last four seasons (1986-1989) of NPS and my own work, Cape Espenberg is the most securely dated beach ridge complex in Kotzebue Sound. The Espenberg series is a mainland attached spit beach ridge complex, 29 km in length, located at the north extreme of Seward Peninsula, on the Arctic Circle. The Espenberg spit is at the south entrance of Kotzebue Sound and lies due south of Cape Krusenstern (Fig. 2.2). In configuration, the Espenberg spit consists of recurved beach ridges mantled by low coastal dunes and resembles the Shishmaref Inlet barrier island coast (J.W. Jordan 1988, 1989, 1990; Mason and Jordan 1989) to the southwest. The Espenberg complex is breached by numerous (>15) channels either created by storm surges or tides.

About 2 km of progadation has occurred at Espenberg since 3500 BP (Mason 1987a, this volume, Ch. 2). Most of the beach ridge progradation occurred during fairweather wave conditions or post-storm recovery periods with little aeolian reworking into higher coastal dunes. Coastal dune formation, sometimes transgressive in nature, has occurred only episodically (Mason 1987a,1988c). Three types of sand ridges occur along the coast of northern Seward Peninsula:

(1) **Dune ridges** are accretional, bell-shaped with slopes up to 30.° Formed as sand from the backbeach is trapped by lyme grass (*Elymus arenarius mollis*), dune ridges may attain heights of up to 20 m, but are generally only 5-6 m in height. Swales between dune ridges are comparatively deep, narrow and are commonly filled by ponds.

(2) **Blowout ridges** form as a consequence of the disruption of the vegetation cover on dune ridges. Such disruption may result from storm surge attack, trampling, fire, plant mortality etc. (Mason 1988c, this volume, Ch 3). Blowout ridges often record several periods of erosion and re-deposition and contain numerous buried surfaces resembling paleosols. Considerable topographic complexity results as eolian erosion produces nested blowouts, coalescing deflation basins and residual dune masses similar to the evolved foredunes of eastern Australia described by Hesp (1988).

(3) **Smooth or planar ridges** are low in elevation, about 2 m above sea level, and

lack accretional sand dunes but may contain traces of former blowout basins. Dunes on these ridges are extremely low. Stratigraphically, smooth ridges show bedding inclined seaward and may correspond to berms found at the highest tide line.[3] Swales between successive smooth ridges are very wide and have allowed for the development of extensive peat deposits and palsas (ice cored hummocks).

The three types of ridges correspond to different depositional environments. Dune and blowout ridges require the (a) a supply of sand on the backbeach, (b) moisture conditions that allow it to be moved; (c) high winds capable of moving the sand and (d) the occurrence of sand capturing plants (Pye 1983b). Dune-building is likely a multi-seasonal process. Sand re-distribution onto the backbeach occurs during the waning stages of storm surges which occur at present with greatest frequency from September to November (Wise et al. 1981). Sand movement and concentration into dunes may occur in late winter/early spring (April through June). Sand capture by grasses occurs in both spring and autumn. Smooth ridges, by contrast, indicate comparatively less windy conditions, the saturation of sands by rain or groundwater and an absence of grasses (if ridges remain too saline). Fair weather conditions prevailing in July/August give rise to most of the swale and smooth ridge accretion.

To distinguish depositional units at Cape Espenberg, several lines of evidence are useful (Mason 1987, this volume, Ch. 2). The most reliable chronological data derives from archaeological sites often consisting of house depressions excavated into dune ridges. Extensive clusters of house depressions ("villages") are particularly common in the youngest ridges. Radiometric (^{14}C) assignments also have been obtained from non-cultural geological contexts (n=5) such as plant material buried by airfall tephra (volcanic ash), grasses within paleosols and marine shells (Table II-g). Generally, the cultural and non-cultural data sets provide a concordant chronology of Espenberg deposition with 37 radiometric dates, including an unpublished series (n=18) collected by the National Park Service in 1988 and 1990 (Harritt 1989, 1990).

Depositional units are also defined on the basis of several other criteria: pedological, granulometric and by landform development. Soils within the youngest

[3] An alternate hypothesis could invoke transient sea level changes of several meters during the time of berm ridge formation. Clark and Lingle's (1979) model for eustatic sea level response does predict that sea levels in the Chukchi Sea were above modern (less than 1 m) from after 3000 until ca. 500 BP.

dune ridges develop as very thin silty laminae in subsurface horizons (Soil Survey 1975), with little or no chemical alteration of grains. Oxidized horizons with higher silt content and grain alteration occur on older ridges with a marked soil profile development on low, poorly drained ridges. Sediment comprising the oldest ridges are intensely oxidized, with some spodsol formation. Some soils have indurated ferricrete horizons, showing the progressive accumulation of ferric oxides. In terms of grain size, older, longer stabilized ridges show finer grain populations whereas younger dune ridges are coarser (Mason 1987, this volume, Ch. 2).

With increasing age, peculiarly arctic phenomena appear on ridges: frost-cracks form rectangular lineaments first appearing on ridges more than 500 m from the coast and inter-swale ponds are increasingly large in size and polygonal in shape with increasing distance from the sea. On the basis of such differences I have (Mason 1987, 1988b, this volume, Ch.2) defined four depositional units.

The four units form a horizontal stratigraphy at Cape Espenberg (Fig. 2.6, 5.1) reflecting alternations between conditions of high intensity storm and those of less storm intensity: Unit I formed between 3900 to ca. 3300 BP, Unit II from ca. 3300 to 2000 BP, Unit III between 2000-1200 BP and Unit IV from 1200 BP to the present.

Unit I consists of a set of low, berm ridges, attached to the mainland on the west and bordered by a shallow lagoon connected with Kotzebue Sound on the southeast. As in all units, Unit I grows longitudinally more differentiated (ie., more ridges, wider swales) with only one or two composite ridges in the west but with six principal ridges (E-20 to E-15) to the widest eastern portion of the unit which is markedly deflected to the southeast. The width of Unit I, 650 m, represents about one quarter of the progradation at Espenberg. Unit I ridges are notable for intense oxidation, the weathering and translocation of ferric oxides down profile to form spodsols (Soil Survey 1975). Two laterally continuous paleosols occur on the oldest Unit I ridge E-20. Unit I is truncated or transgressed in its youngest portion by Unit II ridges. The earliest Unit I ridges are comparatively high, up to 5 m above MSL, containing a significant eolian cover. The beginning of sedimentation within Unit I at Cape Espenberg may be estimated at 4-3.4 kyr BP in reference to the Aniakchak tephra contained within a prominent dated, buried paleosol on the oldest sand ridge, as described above. Archaeologically, only ephemeral encampments of ASTt-related cultures occur on and within Unit I ridges; two are radiocarbon dated to 3570 ±100 BP (ß-19643) and

3750±80 BP (ß-33758) (Schaaf 1988a: 165, Harritt 1990). Unit I accreted between 3900 and 3000 BP and records two differing formation processes: (1) an initial period of dune ridge formation and comparative stasis in shorelines and then (2) a period of rapid progradation.

Unit II describes a prominent blowout ridge (E-14), laterally continuous for the entirety of the Espenberg spit. The Unit II ridge widens to a maximum of about 150 m and grows in height up to 9 m above MSL eastward. In places, the ridge transgresses or truncates the older ridges, but a distinct, uneroded 10°-15° slope distinguishes the younger margin of the unit. At least three cycles of blowout deflation are evident on Unit II ridges, associated with two prominent buried O horizons and several other discontinuous incipient soils. Though archaeological loci are common on the ridge, most of these consist of sparse lithic or ceramic scatters often accompanied by sea mammal oil impregnated sands. The ceramics are distinctively decorated with the linear or check stamp of the Choris or Norton cultures, widespread throughout western Alaska in the third millennium BP (Ackerman 1982, Giddings and Anderson 1986, Schaaf 1988a). Numerous settlements of the ceramic-using, seal-hunting Choris and Norton cultures allow an upper age assignment on Unit II ridge formation as before 2790±80 (ß-33759) and 2285±90 (ß-17968) BP (Table II-g, Mason 1988a, 1988b). The lower age limits of Unit II are probably ca. 3300 BP and reflect an initial period of intensified storm erosion that scarped the older Unit I ridges. In view of its blowout evolution and human occupation history, Unit II seems to have remained adjacent the shore for a considerable period of time and reflects insubstantial progradation.

Unit III includes a region of low, smooth beach ridges separated by swales of over 100 m width. The smooth ridges of Unit III are often discontinuous, extend only several hundred meters in length and consequently form clusters of ridge "fragments." Unit III, about 1 km in width, accounts for nearly half of the horizontal accretion at Cape Espenberg. Groundwater and the active layer of the permafrost table is less than 70 cm from the top of these ridges. Frost cracks outlined by ramparts and crosscutting string bogs have formed under the extensive peat deposits in the swales between sand ridges. Stratigraphically, seaward dipping laminae suggest a marine origin for these ridges; though no dense accumulations of shells or storm beds were noted. Organic horizons (2-5 cm thick) form near the surface under areas of continuous vegetation but subsurface soil horizons are diffuse. Two of the Unit III ridges, E-12 and E-8, are comparatively higher in elevation up to 3 m above MSL; possessing a cover of low 1-2 m deflated dunes and two 2-4 cm thick paleosols. Slightly stronger storms or winter winds may have prevailed during the formation of these ridges.

Few archaeological remains were encountered in Unit III ridges, limiting the chronological assignment of ridge age. Ridge E-12 probably dates to ca. 1800 BP, based on an interpolation from dates on older and younger ridges. Archaeological traces of several Ipiutak (Larsen and Rainey 1948) houses, dating to an weighted average of ca. 1358±41 BP (Harritt 1989) were found on E-8, one of the low (but dune mantled) ridges only 2 -3 m above MSL. The addition of the Unit III ridges record extensive progradation at Espenberg after 2000 BP, continuing until about 1200 BP. The Unit III ridges reflect a time of comparatively infrequent or low intensity storm surges, based on the lack of appreciable dune cover, the comparative low elevation of the ridges and the considerable swale width. Considering the evidence for human occupation despite the low elevation above sea level, we gain an appreciation of the probable infrequency of massive storms during the period between 2000-1000 BP.

During the time interval of 3300-2000 BP a broad flood-tide delta developed between two portions of the Espenberg spit (Figs. 2.6, 5.1). As the tidal inlet subsequently filled during the period from 2000-1000 BP recurved ridges developed toward the center of the former channel. Moore and McCullogh (quoted in Shepard and Wanless 1971:474-5) thought such inlets formed due to the discharge of meltwater during break-up, it seems more likely a storm-related regime is responsible (Hayes and Boothroyd 1969). Similar inlet fill sequences are common on the Shishmaref Inlet barrier islands (J.W. Jordan 1989, 1990). If spring meltwater were responsible the delta should have developed on the ocean side. At some time between 2000-1200 BP a huge washover flat was also present within this breach in the Espenberg complex--similar in form to active washover flats on the present Shishmaref barrier island chain (J.W. Jordan 1989). During the last 1000 years convex seaward dune ridges built from the northwest and covered the washover flat.

Unit IV consists of up to five prominent dune ridges (E-5 to E-1) from 3 to 20 m above MSL. On the seaward aspect the dune ridges are covered with lyme grass (*Elymus* spp.) and are receiving sand from the beaCh. Only two of the five prominent dune ridges are traceable across the entire 29 km extent of Espenberg and numerous smaller dune ridges cluster adjacent to the laterally continuous ridges. The Unit IV dunes vary in height and width, with some up to 50-75 m in width but most are 5-6 m high. Floristic diversity increases with distance from the beaCh. Paleosols were not observed in the youngest ridges, but distinct organic stained horizons were apparent by the E-5 ridge, the oldest ridge of Unit IV. The higher dunes of Unit IV block several of the crosscutting channels in the low-lying planar ridges. Some of the most recent ridges are transgressive in nature, with leeside accumulations of dune sand burying berm ridges of the older sedimentary units. Dune accretion in Unit IV started before 1520 ±60 BP (ß-20028) or 1110 cal AD, based on a calibrated, reservoir corrected geologic ^{14}C date on surficial shell. Radiometric determinations from buried archaeological horizons associated with the western Thule and old Kotzebue cultures (Giddings 1952b) serve as further upper limiting ages on dune formation. Dune-building occurred before 1000 BP, about 700-600 BP and before 300 BP (Harritt 1989, Mason this volume Ch. 2, Table II-g). The seaward aspect of the modern ridges is actively eroding, as indicated by a continuous prominent scarp and measurements indicating 8 to 13 m of retreat during the 26 yr period from 1949-1976 (J.W. Jordan 1988). Scarped ridges from earlier storm events are apparent on the E-5 and E-3 ridges and are dated to about 1000-700 and 500 yrs BP.

In summary, dune-building activity is concentrated in three periods at Espenberg: (1) 3300-2000 BP, from (2) 1200-600 BP, and (3) 250 BP to the present. Smaller dune building events occurred at about 1800 BP (estimated age) and before 1400-1300 BP. If dune building is correlated with increased storminess, as in the North Sea (Jelgersma et al. 1970, Lamb 1982, 1986, 1988) and Australia (Thom 1978, 1984), then the ridges at Espenberg are a proxy climatic indicator. Smooth or berm ridge progadation presumably occurred during "fairweather" post-storm recovery conditions dominated by high pressure conditions as in July/August. During times with less intense and longer storm recurrence intervals, low berm ridges (0.7-1.0 m above MSL) accrete and are separated by wide swales, the product of fairweather accretion. In times with intense storm episodes, berm ridges formed higher in elevation above sea level (1.0-1.7 m above MSL). During the fairweather season, these higher storm-elevated berm ridges were more susceptible to eolian deflation. Dunes then built in two stages: first on the backbeach in response to intense north/northwest winds during winter and provided sand from the beach for incorporation by growing beach grass during summer (Carter 1986, Hesp 1988). The heightened intensity of storminess may be gauged from the creation of tidal channels during the period of dune building 3300-2000 BP.

The Relationship of Cape Espenberg to the rest of Seward Peninsula

Shishmaref Barrier Islands

A series of low sandy, barrier islands lie about 50-150 km to the southwest, updrift from Cape Espenberg. Shore-parallel ridges commonly overlie these islands, informally termed the Shishmaref Inlet barrier island complex;. The Shishmaref Inlet ridges often recurve toward healed inlets with a consistent number of 12 to 20 ridges between sub-complexes (J.W. Jordan 1989). A single, eroded coast-parallel dune ridge (up to 10 m high) shelters most of the landward recurved berm ridges. Due to the absence of archaeological sites more than 500 yrs old, little is known of the chronostratigraphy of the Shishmaref Inlet complex. Several geologic ^{14}C dates (Table II-f) on overwashed, buried turf indicate that progradation predominated 1500-1000 BP (J.W. Jordan 1989, 1990). A shift to an erosional regime and the construction of a high dune ridge after 1000 BP. Overwash events are dated at 980 ±70 (ß-33551), 520±70 (ß-28181) and 320±60 (ß-28184) BP (Table II-f, J.W. Jordan 1989, 1990). The surficial record from the Shishmaref Inlet shows a depositional history similar to that of Espenberg, despite the fact that the barrier islands are updrift and presumably provided some of the source material to construct the Espenberg spit. Hence, the Shishmaref barriers and the Espenberg spit must be deriving sediment from the same offshore sand sources.

Bering Strait: Cape Prince of Wales

Farther south of Espenberg, at the Bering Strait, a sand ridge complex at Cape Prince of Wales extends for 30 km and encloses Lopp Lagoon (Fig. 5.1b). The Wales ridge complex is 3 km wide and composed of only 8 to 12 principal ridges, with wide swales between many of the earliest ridges. The topography of the Wales ridges is irregular due to the extensive post-depositional expansion of lakes cross-cutting the ridges. Little archaeological survey data or geologic maps exist for the Wales complex, but I can offer a tentative map of its depositional units and a few observations about its history are possible (Fig. 5.1). Of the four depositional units, the oldest **Unit I** and **I-b** are the most complex and widest--over 1 km. Wide swales, filled by large globular-shaped lakes, characterize this period, implying long recurrence intervals between storms. In topographic complexity and frost-crack pattern the Unit I of the Wales complex resembles Cape Krusenstern (see below). Few blowouts or exposed, unvegetated areas are observable on photos. **Unit II** is marked by a single laterally extensive ridge. The most recent ridges of **Unit III** are closely spaced and formed within 100 m of the modern shore.

The age of the Wales depositional units may be estimated from archaeological sites about 750 m landward on the third beach, paralleling the single ridge of Unit II. Lying at the northeast extreme of the Wales ridges, charcoal from the Agulaak Island and Kugzruk Island sites bracket a Norton occupation ca. 2700-2300 BP (900-300 cal BC) (Table II-e) similar in age and character to that on the E-14 ridge of Cape Espenberg (Giddings and Anderson 1986:30). Most of the progradation at Wales occurred during the period before 2600 BP (850 cal BC), a similar situation to that of Espenberg. After 2300 BP (300 cal BC) comparatively few ridges were added at Wales.

East Kotzebue Sound

Choris Peninsula

The knob of schistose bedrock (Patton and Miller 1968) forming Choris Peninsula (up to 100 m above sea level) lies directly to the southeast of Cape Espenberg, across 85 km of open water in Kotzebue Sound (Fig. 5.1). Within three former embayments of Choris Peninsula, pea gravels have formed beach ridge plains. The sequence of nine beach ridges (Fig. 4.2) on the westernmost complex (Choris A) parallels the stratigraphy of Espenberg, both in plan and in relative height (Mason 1987b, this volume, Ch.4). Four depositional events are also evident within the west Choris A complex, with wider, higher ridges occurring only at two locations. **Unit I** includes only a single ridge at the base of the bluff. **Unit II** consists of the C-8 ridge, 30 m wide and 2.75 m above MSL. **Unit III** defines six, narrow (<20 m in width) ridges about 2.0-2.5 m above MSL, separated by wider swales. **Unit IV** is the most seaward ridge, C-1, the most massive of the Choris ridges, 90 m wide and 4.0 m above MSL. Several age assignments are available (Table II-h) from Unit II based on the Choris occupation at

2646 ±177 BP (P-203) (Giddings and Anderson 1986:30). Norton aged cache pits on the C-5 ridge in Unit III are dated at 2190 ±51 BP (P-611) (Giddings and Anderson 1986:30). The Choris ridge, Unit II, correlates with the blowout Choris and Norton Unit II ridges at Cape Espenberg, which also dates to 3000-2000 BP. After ca. 2100 BP (or 180 cal BC) the accretion rate of the gravel ridges at Choris increased in terms of horizontal distance but with lower ridges, implying less intense storms in this period, as at Espenberg. During comparatively recent times--probably the last 500 years--a single ridge has formed. Though undated radiometrically,the modern ridge is the widest and highest (up to 4 m above MSL) of all Choris ridges and contains only late prehistoric and modern settlements. Since gravel ridges may be assumed to respond only to storm events, it may be argued that storminess has increased at a time after 2000 BP--and this event must be correlated with the most recent unit IV at Espenberg. The alignment of Choris to the west allows the impact of only a limited number of intense storms--from the west northwest (Fig. 5.1).

On the eastern aspect of Choris Peninsula, fifteen low gravel ridges have added (Choris C complex), due to deposition within the comparatively small Eschscholtz Bay which has only about 50 km of maximum fetch from the east. Eolian deposits (silty sand) occur above the oldest ridges and contain ASTt related artifacts probably about 3300-3500 years old. Otherwise, the eastern Choris ridges are divisible into three depositional units: the oldest unit I, ridge Ch-C-15, is capped by over 50 cm of medium sand, vegetated by crowberry, contains diagnostic Norton lithics probably dating to ca. 3000-2000 BP Units II and III are unvegetated and can only be distinguished by differences in swale width. The origin of the eastern Choris ridges is problematic. The accumulation of sand at the base of the bluffs is a partly an aerodynamic result based on the longer distance transport of sand across gravel noted by Bagnold (1954:72) and may not impart any climatic or provenance data. However, three contradictory climatic related hypotheses may be advanced to explain this sand accumulation: (1) massive erosion of the Choris Peninsula occurred at some time before the Norton occupation, ie. pre-2000 BP. A small creek does drain the interior of the peninsula and debouch into Eschscholtz Bay through the beach ridge complex, which deflects the creek's course; (2) the sand derives from a limited offshore source later exhausted; or (3) the sand entered Eschscholtz Bay from the Buckland River, at the bay's southeastern margin. At present, the first or third hypotheses are equally likely.

North Kotzebue Sound

Cape Krusenstern and Sisualik

Beach ridge progradation in the Chukchi Sea reached its most complex evolution at Cape Krusenstern, located at the northern portal of Kotzebue Sound, due north of and opposite Cape Espenberg (Fig. 5.1). The orientation of the coast at Krusenstern shifts radically from nearly east/west to nearly due north/south. Waves reaching Cape Krusenstern may originate from several points of the compass, from the northwest, with fetch over 700 km, and from southwesterly storms near the Bering Strait at over 500 km of fetch distance. At present such storms are particularly common in August. About 70 principal ridges have accreted at Krusenstern (Fig. 6.2) since the stabilization of sea levels ca. 4000 BP.[4] Six principal depositional units are notable at Krusenstern subdivided by prominent erosional disconformities well-dated by adjacent distinctive archaeological cultures (Giddings 1966). Evidence for beach ridge progadation starts with the occupation of ASTt peoples on the K-90 ridge, as well as on K-102-104 and other ridges, probably date to 4200-3700 BP (Giddings and Anderson 1986, Anderson 1988). The earliest ridges, **Units I** and **II**, at Krusenstern are markedly altered by the development of a network of frost cracks and the expansion of lakes due to peat degradation. After or during the 3000 BP (1047 cal BC) datum represented by the Old Whaling culture occupation on the K-53 ridge, massive erosive events occurred at Krusenstern, resulting in a significant truncation of the beach ridge complex and re-deposition downdrift to the southeast, producing **Units III** and **IV.** (Mason and Ludwig, in press, this volume, Appendix) Development of this pronounced unconformity after ca. 3000 BP on Krusenstern coincides with the building of storm ridges at Espenberg and Choris.

A differing depositional regime prevailed at Krusenstern in the millennium 2000-1000 BP, leading to southwestward progradation of nearly 750 m, almost a third of the total at Krusenstern. This progradation is well-dated by the superimposed cultural occupations on ridges K-35 to K-9 by peoples of the Ipiutak (1660-1200 cal BP) and western Thule cultures. The progradation was favored by lessened storm intensity

4 Giddings' (1963, 1967) count of 114 ridges usually quoted counts many discontinuous ridges and is probably not accurate, for reasons explained in Mason and Ludwig in press, this volume, Appendix

from the southwest and a steady state of uninterrupted longshore transport from north to south (cf. Moore 1966). However, at ca. 1200-1100 BP (1130-1000 cal BP) radical changes in deposition occur at Krusenstern, correlated with similar changes at Espenberg and Choris. Again, increased storminess is likely the causative factor. During the last several hundred years, Krusenstern has once again witnessed substantial displacement of beach gravels from north to southeast. As Moore and Giddings observed, the trend and importance of longshore transport during erosional cycles is revealed in the truncated northwest segments at Krusenstern (Giddings 1966:Fig.6, Mason and Ludwig in press, this volume, Appendix) .

In addition, in the northwest portion of the complex the youngest nine ridges coalesce into a single high, composite ridge (Giddings and Anderson 1986: 41). On northwest ridges of Krusenstern, younger beach deposits transgress and bury sites of the predominantly seal-hunting Birnirk culture (Bockstoce 1979), dated to 1180±110 BP (K-851) and 1100±100 BP (K-816). The erosional facies (**Unit VII** in Fig. 5.1) re-transported to the southeast contain younger aged cultural remains of the widespread, whaling western Thule culture dated to 1070±100 BP (K-817) to 770±120 BP (K-281).

To the southeast of Krusenstern, the situation at Sisualik, across from the mouth of the Noatak River, is similar to Krusenstern. J.W. Jordan (1987) distinguished four depositional units [Fig. 5.1(e)]. Two sets of early ridges,[5] lie at the base of bedrock cliffs and trend northeasterly, at variance with the recent spit growth to the southeast. Unit II is formed by a narrow, composite ridge (about 2 km long) and the coastward-scarped eastern portion of a spit oriented due west/east. More recent spit growth, recurves profoundly towards the entrance to Hotham Inlet, containing Units III and IV. Frost cracks and large, amorphous inter-swale lakes are common in only the earliest ridges. No radiocarbon dates are available from Sisualik, so that only tentative correlations are proposed here. The earliest ridges, **Unit I**, are probably 4000-3000 years old, based on topographic (ie. frost-cracks and lake morphology) and vegetational similarities with the earliest ridges at Krusenstern. The narrow multiple ridge and west/east spit, **Unit II**, reflects conditions during the period 3000 BP to 1500 BP and possibly up to more recently. The small sand spit built in two periods, oriented west to

[5] The earliest portion at Sisualik was apparently unrecognized by Giddings and Anderson (1986: 20) who thought Sisualik was the youngest beach ridge complex.

east, started to form before 1000 BP. A period of rapid spit growth (Moore 1966) occurs after an undated "early" western Thule occupation estimated to 1200-1000 yrs BP (Giddings and Anderson 1986:86ff).

Tentatively, at Sisualik, prograding conditions prevailed 4000-3000 BP and after 1000 BP. The growth of sediment-limited Sisualik seems to represent a local phenomenon resulting from the updrift erosion of older spit materials with re-deposition only a short distance downdrift. A period of rapid erosion seems to have occurred 1200-1000 BP and generated the most recent spit.

Point Hope

The distinctive beak shaped spit at Point Hope marks the northernmost limit of the southeast Chukchi Sea (Fig. 5.1). At Point Hope the trend of the coast shifts abruptly and no longer faces Bering Strait. Consisting of cobbles and granules, the Pt. Hope spit has built from east to west across the mouth of Kukpuk River. Thin sand deposits (0.5m), probably derived from the Kukpuk River, cover the oldest ridges (Larsen and Rainey 1948:22,40-41, Sharma 1972). Depositional units are definable on the base of differences in swale spacing (dates in Table II-j). The oldest, highest (about 2.3 m ASL) beach ridges at Point Hope appear to be 2070±100 (K-725) (Gal 1982) to 2050±70 BP (K-3543) yrs old (Larsen 1982, written communication) occupation of the (Near Ipiutak) Norton ceramic using culture (Larsen and Rainey 1948). By extrapolating from the 2000-yr age estimate on the oldest ridges and native informants, Hosley estimates it took 80 yrs to build a beach ridge at Pt. Hope (I calculate about 70 yrs: 2000 divided by 29). This tempo of beach ridge addition at Point Hope parallels the spacing of ridges at Cape Espenberg so that periods of narrow swales correlate with more frequent storms at: 0-285 BP (ridges PH 1-3), 857-1071 BP (PH 12-14) and 1714-1856 BP (PH 24-25) (Mason1988, unpublished calculations). The occupation of the late prehistoric village of Tigara on ridges PH 7-10 dates from at least ca. 1708-1820 AD (ca. 250-125 BP) on the basis of dendrochronological correlations (Giddings 1941:84) with Kobuk River valley sites.

Bering Sea Beach Ridges

Though not as extensive as those in Kotzebue Sound, beach ridges formed at several locations along the shores of the Bering Sea. The two most securely dated complexes are the Gambell foreland, at North Cape on St. Lawrence Island and east of Cape Nome, at the entrance of Safety Sound, on the south shore of the Seward Peninsula. The wave climate of the Bering Sea is effected by much higher energy levels when compared with the Chukchi Sea. The Bering Sea has a tidal range of 0.4-1.2 m coupled with greater wind fetch and maximum storm surge heights of about 4.0-5.0 m (Sallenger 1983) for Norton Sound and the north Bering Sea. Hence, progradational sedimentary features are less frequently preserved. Winds into Norton Sound are predominantly (40%) from the southwest quadrant (Cacchione and Drake 1979:37).

In terms of available sediment, the Gambell and Nome gravel ridges are cobbles and/or sand eroded from nearby cliffs and headlands. Finer sized particles, sands, at Nome originate from the Yukon Delta, due south (Cacchione and Drake 1979:44). High early summer discharge of sands onto the prodelta exceeds the capacity of bottom currents and maintains a reservoir of offshore sand. Though most coastal modifications occur in the open water period, the occasional winter storm surge event may be an important geological agent.

The northerly recurving spit of Point Spencer at the mouth of Port Clarence has been briefly studied geologically (Black 1946). The sand and gravel spit records a eastward trend in earlier portions of the spit, with a high ridge at the western margin at variance with the general trend. A recent portion of the Pt. Spencer spit contains Ipiutak cultural remains (Larsen 1979/80) probably 1500-1000 yrs old, based on the dates from Pt. Hope and elsewhere. Despite this datum point, no estimates of age can be offered for progradation rates at Point Spencer, though it seems the spit has a considerable antiquity.

Cape Nome/Safety Sound

At Cape Nome both gravel beach ridges and a 7.3 km long sand spit formed in the late Holocene. Seven predominantly gravel ridges issue eastward 4 km from the 197m high Cape Nome cliffs. The seven ridges prograde seaward as at other northwest Alaska complexes. The sand spit extends farther to the east beyond the gravel ridges and contains multiple subtly recurved ridges. The two different types of sedimentary features and clast size seem to reflect differing depositional regimes. The elevated (up to 4 m above MSL) gravel ridges represent high magnitude, low frequency storm events while the low sand spit, frequently overwashed by storms, probably builds during fair weather conditions dominated by longshore sand transport which largely bypasses the gravel ridge complex.

Extensive archaeological excavations by Bockstoce (1979) from the gravel ridge complex provide minimum ages[6] for the elevated sea levels associated with storm activity (Table II-d). On the earliest Cape Nome beach (N-7) Arctic Small Tool assemblages probably dated 4500-3500 BP are from a buried sod layer topped by 70 cm of sand and overlain by younger cultural materials of the early phase of the Norton tradition dating 2216 ±97 BP (I-6085). Though the earliest N-7 ridge remained attractive for settlement until 1719 ±181 BP (I-5378), a more seaward ridge, ridge N-6, had built by 1600 BP. The high N-6 ridge also continued to be attractive for another thousand years, based on ^{14}C dates from houses of Thule people only 400 yrs in age. Several ridges added after a Thule occupation on the N-3 ridge.

The Cape Nome gravel ridges show that major storm events occurred before 3000 BP and 2400-2200 BP. A lessening in storm intensity occurs about 1700 BP, and several ridges built before 300 BP. The age of the Safety Sound sand spit is unknown; Bockstoce (1979:19) reports that only late prehistoric occupations lie on the spit. Much of spit construction should date in the period between the 2200 and 1200 BP, if it is related to less intense storm surges, as is the major period of progradation at Espenberg. Thus, the growth of the Safety Sound deposits parallels the history of the Kotzebue Sound ridges, but with distinct differences due to its southern exposure and greater fetch distances.

St. Lawrence Island: Gambell

The Gambell foreland on St. Lawrence Island, lies at 7 m above MSL and contains thirteen principal gravel ridges building from the south to north and divisible into four depositional units (Collins 1937, Mason and Ludwig in press, this volume Appendix). A prominent disconformity, the G-6 ridge subdivides the complex, with earlier ridges oriented west to east. Stylistically distinctive and reasonably well-dated archaeological cultures occur on three of the depositional units (dates listed in Table IIa, aa). The earliest ridges--**Unit I**--contain an Old Bering Sea occupation dated to

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[6] Bockstoce (1979) uses the 5730 half life for his ^{14}C assays (listed in Table II-d), corrected here to the 5568 half life generally accepted, cf. Taylor (1987).

1800-1600 BP. The disconformity (G-6) is dated at 1130±70 BP (B-3210) in reference to the Punuk occupation (Bandi 1984:61). Sedimentation regime shifted after 1000 BP when several ridges added to the north, but apparently were unoccupied by people, inferred by the absence of archaeological sites. A third shift in sedimentation regime occurred some time during the last few centuries, before the occupation of the late prehistoric village of Seklowaghet.

Hence, at Gambell, progradation predominated during the period 2000-1200 BP, an erosive regime followed at 1200-900 BP, succeeded by progradation and a return to erosive conditions in the last several hundred years. This pattern broadly parallels that of the rest of the Bering Sea and Kotzebue Sound ridge complexes.

Comparisons with other Alaska Coastal and Marine Records

Oceanographic cores from Norton Sound provide direct, parallel evidence for increased storminess during the late Holocene. Epiclastic terrestrial peats below discrete sand units within the top 20 cm of three cores date from 3590 ±140 BP (USGS-354), 3070±40 (USGS-353) (Robinson and Trimble 1983:145) and 2090±120 BP(USGS-183) (Robinson and Trimble 1981:313) (Table II-c). C.N. Nelson (1982) interprets these sand beds as evidence of storm surge activity. Sand layers dating after 3700-3300 BP are found on elevated bluffs along Bristol Bay and are interpreted by Lea (1989b) as tsunami or storm surge deposits.

The onset of storm activity in the Bering Sea may also be gauged from the initiation of chenier ridge deposition along the margins of the Yukon Delta. The earliest chenier storm ridges date from 2420±80 (USGS-214) and 2570±70 (USGS-226) BP (Robinson and Trimble 1983:144-5)(Table II-b). Subsequently, only beach ridges were added 1900 to 1500 BP (based on dates from subsurface "basal" peats). Non-chenier mud deposition has dominated since about 1430 ±50 BP (USGS-212) (Robinson and Trimble 1983:144, Dupre 1984, written communication). After 1000 BP the sediment from the Yukon River constructed the present deltaic complex to the north of the chenier plain and contributed less sediment to the ridges.

At Point Barrow Hume (1965) recorded transgressive gravel ridges (+0.6-1.0 m above MSL) dated between 1750-1500 BP and 1000-900 BP (Table II-k). Similarly, Pewe and Church (1962) propose that beach ridges, 1 to 2 m above modern sea level, at Pt. Barrow resulted from high eustatic sea levels prevailing from 1200-1000 BP It is more likely that sea levels were elevated due to lowered pressure associated with storm activity. These periods of intensified storm activity parallel the other Chukchi and Bering Sea records. A brief period of heightened storm activity did occur at Espenberg after 2000 BP and before 1400 BP (the E-12 ridge) while transgressive dunes started to build ca. 1200 BP.

Summary of Northwest Alaska Beach Ridge Chronologies

The history of beach ridge complexes in western Alaska reveals that (Fig. 5.2):

(1) During 4000-3500 BP the initiation of sedimentation is recorded at several locations: Capes Krusenstern and Espenberg, and probably at Choris Peninsula, Safety Sound, Sisualik and Wales. No evidence of ridges for this period is evident on the surface for the complexes at Pt. Hope and Gambell.

(2) From 4000 until before 3000 BP extensive progradation predominated at Krusenstern, Espenberg, Wales and probably at Sisualik. Such conditions are probably linked to fewer or less intense storm surges.

(3) The millennium 3000-2000 BP is marked by erosion and storm-deposited ridges throughout Kotzebue Sound. A single ridge of high dunes formed at Cape Espenberg and wider gravel ridge formed at Choris Peninsula;

(4) The period 2000-1200 BP witnessed substantial progradation at nearly all the complexes except Wales, but including Sisualik where subsequent erosion has truncated the record from this depositional period;

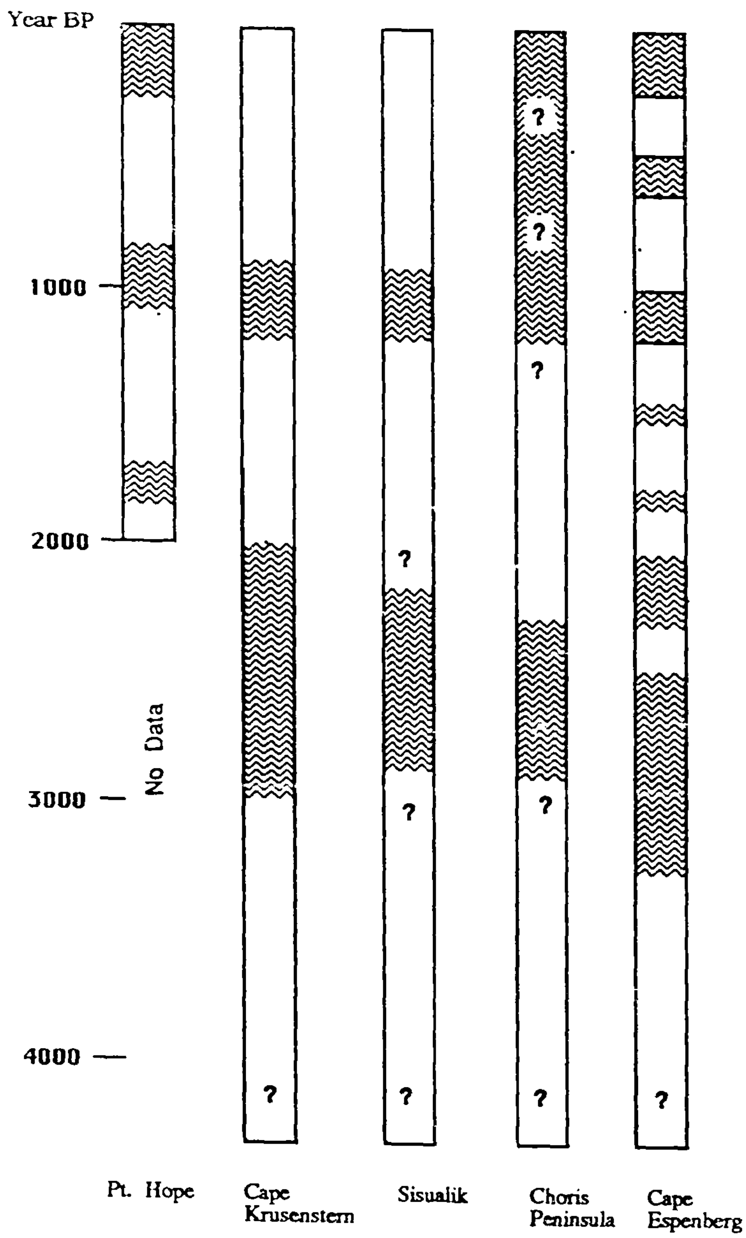

Fig. 5.2. Tentative temporal correlations between the major Chukchi Sea beach ridge complexes. Progradation occurs ca. 4000-3300 BP and from 2000-1000 BP in nearly all complexes. Erosion predominates during the intervening periods.

(5) In the last millennium, from 1200 BP to the present, storm deposited ridges, composite ridges or disconformities occur at all ridge complexes, especially from ca. 1100-850 BP and from 300 BP to present. Localized erosion with re-deposition only a short distance downdrift is common at Krusenstern, Sisualik and Point Hope.

Conclusions:

The Pattern of late Holocene Climate in Northwest Alaska.

The differing orientations and depositional histories of northwest Alaska beach ridge complexes allow the construction of a diagrammatic sketch of late Holocene paleo-storm records (Fig. 5.2). To summarize, several complexes contain parallel progradational sequences: Cape Espenberg, Cape Krusenstern and Choris Peninsula. Progradation occurs at these complexes from ca. 4000-3000 and from 2000-1000 BP. Partial records of progradation for the later period of 2000-1000 BP are documented at Pt. Hope and Gambell, which lack ridges older than 2000 BP. Extensive progradation occurs ca. 4000-3000 BP at Sisualik and Wales. Erosional disconformities and shifts in sedimentation regime characterize the period ca. 1200-900 BP at several of the complexes:Gambell, Cape Espenberg, Cape Krusenstern. Sisualik appears to be out of phase with the other complexes, with extensive spit building occurring in the last 1000 yrs, however, this progradation probably reflects a massive erosional episode ca. 1200-900 BP, as at the other complexes and the localized re-deposition is similar to the most recent units at Krusenstern.

Differences in depositional histories may be linked to (a) sediment availability and grain size; (b) orientation in relation to prevailing storm tracks. Further, the southeast Chukchi Sea beach ridges are part of a single depositional system, in some measure controlled by the dominant currents. The formation of beach ridge plains (also termed cuspate forelands) is linked by Shepard (1973:150) to the high velocity currents adjacent capes and deposition in a leeside slackwater zone associated with back-eddies. Precisely this situation occurs along the Chukchi Sea, as seen above. Wales, at Bering Strait, contains extensive deposits only in the early portion of the record, implying that conditions in recent times have varied considerably. Perhaps, increases in current strength are responsible.

Shifts in sediment availability may provide an explanation for gaps in the depositional record at several complexes. At Sisualik and Wales, the middle period is either absent or truncated. Since both locations lie within longshore transport systems possibly represented by other complexes, it is necessary to relate one part of the system to another. Quite possibly storm or wave intensity could have impacted a particular stretch of coast severely and predominantly caused erosion. This is probably the case at Wales, adjacent the Bering Strait, where geostrophic currents are intense at present (Coachman and Aaguard 1975). If Sisualik Unit I is indeed 4000-3000 yrs old, then Sisualik and Krusenstern were both prograding simultaneously. However, if the earliest ridges at Sisualik date from 3000-2000 BP progradation at Sisualik derives from the erosional period at Krusenstern due to longshore bypassing at Krusenstern. Without precise dating of Sisualik it is difficult to assess the likelihood of either possibility. However, only a small amount of prograded deposit remains from the period before 1200 BP at Sisualik, unlike the other complexes. This circumstance may be again related to the precise stretch of coast impacted by the cumulative set of storms during the period and could serve as a record for storm tracks, when the unit is dated. If fewer, strong but less intense storms affected the coast updrift from Sisualik, perhaps little sediment was available for spit construction.

In this way, the history of storm activity in northwest Alaska may translate into a record of the patterns of wind direction affecting the Chukchi Sea coast, as proposed (but not elaborated) by Moore and Giddings (1961).Massive storm events capable of impacting both Espenberg and Choris could only be directed by winds from the northwest since Choris has an especially small window for maximum fetch (Fig. 2.1). Thus, storms from the northwest probably occurred with greater frequency during the periods 3000-2000 and 1000-0 BP. If more northerly, coast-parallel storms were frequent this situation could explain the lack of early (pre-2000 BP) ridges at Point Hope. Probably such northwesterly storms correlate with September conditions but could relate to less ice cover in October.

The situation at Cape Krusenstern for the period after 3000 BP is more complicated, however. The trend of post-3000 BP ridges lies to the east-southeastward downdrift from the disconformity marking the 3000 BP datum. Such a circumstance may be explained by reference to the effects of storms entering Kotzebue Sound from the southwest, ie. channeling winds and currents through Bering Strait (Wise et al. 1981). As southwesterly winds enter the Chukchi Sea, surface currents are directed onshore to the Seward Peninsula, producing an increase in water levels, a coastal set-up (Vincent 1986), but result in a downwelling force toward the shelf. Thus, net transport of sediment is seaward. As southwesterly currents impact Cape Krusenstern at a perpendicular, once again coastal set-up occurs and net flow is offshore (Niedoroda et al. 1985:fig.8-11). After the storm subsides, lower energy longshore transport carry the eroded materials east-southeast.

At Espenberg, transgressive dunes develop at ca. 3300 to 2000 BP. If, as in the North Sea (Lamb 1982) and in Australia (Thom 1978), transgressive coastal dunes are correlated with glacial expansion, then these dunes mean increased storminess during the summer resulting in snow accumulation (hence glacial expansion) in the mountains. During the next period, 2000-1000 BP, based on the reduced wind intensity at Espenberg and the smaller storm ridges at Choris, we can infer that during 2000-1000 BP late winter, summer and early fall were dominated by stable air masses, with far fewer North Pacific storms penetrating the Chukchi Sea. Such "fairweather" conditions dominated deposition, and occur presently during summer (July/August) when low or high pressure systems. The path of fall storm activity may have less affected the Chukchi Sea, remaining restricted to south of Bering Strait. Thus, either storms declined in autumn months of September/October--or ice formed earlier than at present. The climatic implications of the two patterns seem contradictory. The elimination of the stormy period could be linked to increased ice cover during the presently stormy months of September, implying colder temperatures, not necessarily the case since the present prevalence of high winds may preclude ice formation, as in Bering Sea (Stringer 1982).

The record at Cape Espenberg and Cape Krusenstern, Choris Peninsula and other northwest Alaska beach ridges provide a climatic proxy--the extent of wind associated with the prevailing synoptic weather systems. Thus, we may correlate beach ridge sedimentation in northwest Alaska with large scale climatic anomalies in the northern hemisphere. Ridges associated with higher storm intensities occur during two periods: 3300-2000 BP and at times from 1200 BP to the present. These patterns are correlative with similar cyclicity evident in the Greenland ice cores (Dansgaard et al. 1984) and in synoptic reconstructions for the Canadian High Arctic (Alt 1983). However, work at present is preliminary and subject to re-interpretation with new data.

Appendix

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Resurrecting Beach Ridge Archaeology: Parallel Depositional Records from St. Lawrence Island and Cape Krusenstern, Alaska

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Abstract

Archaeological sites on gravel beach ridge plains offer a treacherously facile method of reconstructing cultural chronology based on the assumption that settlements were preferentially situated nearest the sea. The initial phase of beach ridge methodology in Alaska dates from its 1930's use by Henry Collins at St. Lawrence Island and its 1950's use by Louis Giddings in Kotzebue Sound. Numerous questions of cultural and depositional chronology remain unresolved. At Gambell, on St. Lawrence Island, three sets of ridges span the period since about 2000 BP, with a prominent disconformity after Punuk culture times at ca. 1100 BP. Reviewing the ^{14}C dates (n=43) we find that the Gambell sequence broadly parallels that of Kotzebue Sound, especially in the similar erosional disconformity after 1200-1000 BP, related to increased storminess in the North Pacific. The Cape Krusenstern sequence is only loosely constrained by ^{14}C dates (n=33) disproportionately concentrated on 7 of the 114 ridge fragments. The dating of early Choris culture is especially problematic, which seems to occur both before and after the Old Whaling culture, well-dated at ca. 3000-2900 BP on the 53rd ridge. However, re-analyzing the depositional sequence, we find that the some of the more easterly Choris ridges probably represent erosional events after the Old Whaling occupation.

Introduction

J. Louis Giddings (1967:18ff) re-discovery of "beach ridge archaeology" in the mid-1950's has assumed the magnitude of an epiphany. Even undergraduate archaeology texts (Thomas, 1989: 275ff) now underscore the importance of the horizontal stratigraphy present in the successive increments of shore face within such deposits. The origins of beach ridge archaeology, however, lie outside of Kotzebue Sound, the arena of Giddings' seminal studies. Edward W. Nelson (1899:265-266), traveling along the Chukotsk Peninsula, first observed abandoned villages unrelated to present shorelines and postulated relative sea level changes to account for the present location. Working on St. Lawrence Island during the 1930's, Henry Collins made similar observations as part of his investigations at large village sites on the Gambell beach ridge plain.

Recently, in 1988, the National Park Service (NPS) distributed the long-awaited final report on the Beach Ridge archaeology of Cape Krusenstern (Giddings and Anderson 1986). The NPS has also recently acted to re-invigorate beach ridge studies in Kotzebue Sound with the 1986 Bering Land Bridge survey along the north Seward Peninsula coast by Jeanne Schaaf (1988) and its support of the geological researches of Jordan (1989) at Kividluk and Mason (1987, 1988a) at Cape Espenberg. At Cape Espenberg, the NPS has recently undertaken an extensive testing program led by Roger Harritt (1989). Within the Cape Krusenstern Monument itself, Douglas Gibson and Dale Vinson have completed two seasons of additional survey for the NPS. It is particularly timely, then, that we re-evaluate the accomplishments of Collins at St. Lawrence Island and Giddings at Cape Krusenstern.

Re-interpreting the Record of the Beach Ridges on St. Lawrence Island

The Gambell Beach Ridge Plain

Located at the northwest extremity of St. Lawrence Island at 63° 47' N., 171° 50' W., the Gambell beach ridge plain lies south of Bering Strait, within the Bering Sea, about 500 km southwest of Cape Krusenstern in the Chukchi Sea (Fig. 2.1). Forming a rectangular sediment package, the Gambell gravel ridges extend 1.2 km west from the

180 m high cliffs carved in the quartz monzonite of the Mt. Chibukak pluton (Patton and Csejtey, 1980). The Gambell plain lies up to 7 meters above sea level and was thought to reflect the activity of waves approaching from the northeast (Hopkins 1976 in Bandi, 1984:33).

Research at the five principal archaeological sites on the Gambell beach ridges (old Gambell, Seklowaghyaget, Ievogiyoq, Miyowagh and Hillside) was initiated by H.B. Collins (1937: 26ff) with substantial block excavations at the "Miyowagh" [Mayughaaq (XSL-002), according to Crowell, 1985: 43] site in 1930. Further excavations at Miyowagh in the 1970's by Bandi (1984) revealed an extensive cemetery. D. R.Yesner conducted a brief excavation and survey in the late 1970's for the U.S. Public Health Service (Crowell, 1985:43).

In 1930 the village of Gambell lay at the southwest boundary of the beach ridge complex. Using this point of reference, Collins (1937: 33) offered the initial postulate of the beach ridge method based on the successively landward positions of the five older Gambell area sites:

> A striking feature of the gravel plain on which these four old sites are located is the series of old beach lines--parallel ridges of gravel piled up through the action of sea ice, waves and currents--which extend westward for three-quarters of a mile [1.2 km] from the base of the plateau to the slight elevation occupied by the present village.

This relative age scheme was derived "in view of the universal tendency of the maritime Eskimo to locate their village[s] within easy access of the sea or any other body of water (Collins, 1937:34)."

Collins (1937, 1964) counted only seventeen ridges within the entire Gambell complex (Fig. 6.1). Four principal cultural periods are represented on the Gambell ridges: Okvik/Old Bering Sea (OBS), Punuk, late prehistoric and historic. The definition of the four cultures is based on stylistic differences, since the entire cultural sequence "fit[s] into a broad cultural continuum, marked by a rather unchanging ecological adaptation" (Ackerman, 1962:27). Controversy (summarized in Ackerman, 1984:108) exists concerning the priority of the Okvik or Old Bering Sea styles and we concur with Ackerman (1984:108) that the two most likely represent "regional variants of the same culture." Overlooking the entire complex, at its southeast margin, lies the

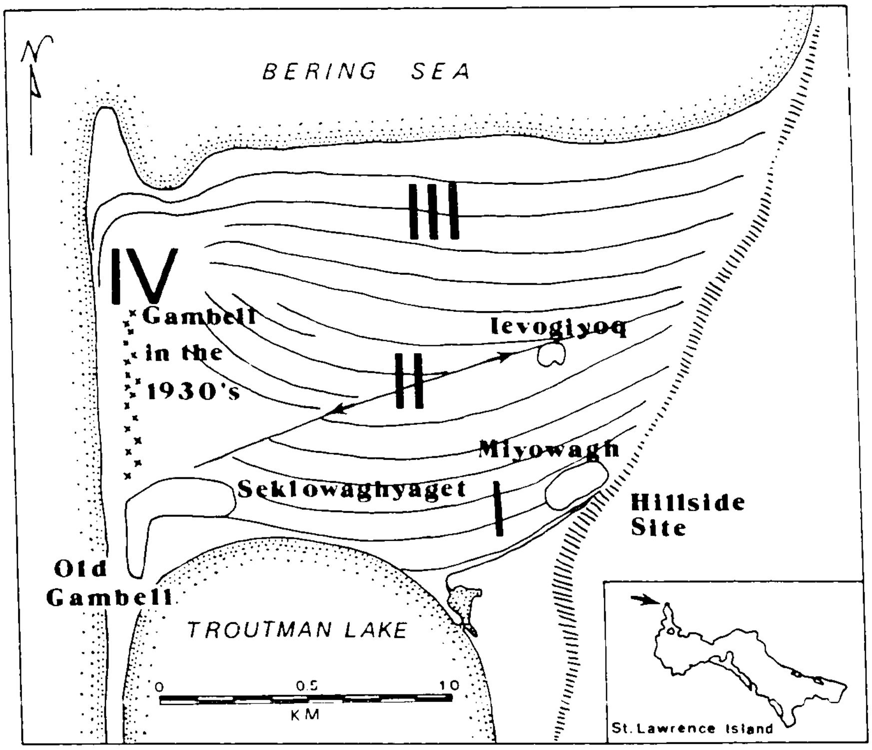

Fig. 6.1. Depositional units at Gambell, as re-interpreted here, modifying Collins' (1937, 1964). A prominent disconformity across (Unit II) the middle of the complex dates after Punuk times, 1200-1000 BP and indicating that an erosional regime prevailed in the Bering Sea.

Hillside site, thought to pre-date the formation of the Gambell ridge plain. Only Okvik/OBS materials are known from the Hillside site. Miyowagh is the oldest beach ridge settlement, located on the first and second ridges and contains OBS remains overlain by Punuk materals. The Punuk culture Ievogiyoq site, on ridges 6 and 7, is positioned at a critical juncture in the depositional history of the ridge system and will discussed later. The two other sites contain only late pre-historic and historic artifacts not dated radiometrically and lie at the western limit of the complex.

Collins (1937:33ff) offered several noteworthy observations concerning the geometry of the ridges:

(1) the earlier ridges curve only slightly;

(2) after the formation of the first six ridges the shoreline changed radically and eroded the outer or western ends of the earlier ridges leaving a beach cutting obliquely to the previously formed ridges;

(3) subsequently, a new series of east/west ridges were formed.

The prominent erosional disconformity provides a basic reference line for the subdivision of the depositional history of the Gambell beach ridges and is visible even in a small scale (1: 60,000) 1978 aerial photo. The older ridges, our **Unit I**, contain the Miyowagh and Ievogiqyoq sites (Fig. 6.1). The disconformable ridge 7 may be defined as **Unit II.** The succession of ridges north of and younger than the disconformity forms **Unit III**. In the recent past, at the time of Seklowaghyaget and Old Gambell, a series of ridges has built from south to north along the western margin of the entire complex. These south to north ridges form **Unit IV**. Archaeological loci occur on three units of the complex--all except the Unit III ridges which immediately postdate the disconformity.

Examining this depositional sequence, we propose that the building of the Gambell reidge plain actually proceeded as a result of longshore transport of gravel from south to north. Thus, a thin strip of gravel existed along the west shore throughout the entire period and maintained Troutman Lake as a separate body, similar to other lakes on the north shores of Kotzebue Sound (Hopkins, 1986). In this interpretation [differing from Hopkins (1976), quoted in Bandi (1984)], the disconformity at Unit II might represent either a shift to prevailing wind pattern, a decline in available sediment, increased erosion or a combination of the three. A field program of sedimentological analysis, using grain size parameters, could distinguish the more likely of the possibilities.

The Dating of the Gambell Depositional Units

Radiocarbon Dates Run in the 1950's

A substantial body (n=43) of radiocarbon dates (Tables II-a, aa, b) exists for the Gambell beach ridge complex (Arnold and Libby, 1951; Bandi, 1984; Collins, 1953; Rainey and Ralph, 1959; Ralph and Ackerman, 1961). Samples collected in the 1950's include three (one re-dated) from the Hillside site, six from Miyowagh and two from Ievogiyoq (Table II-a).

Dating the Hillside site (Table II-a), which supposedly precedes deposition of the Gambell ridges has been confounded by one early date of 2258±230 BP (C-505) published by Giddings (1960) for his Okvik house. The date was obtained by Libby (Arnold and Libby, 1951) using the now outmoded solid carbon method (cf. Taylor, 1987: 76-77) on spruce wood. The large standard deviation (230 yrs) highlights the large counting error often associated with the solid carbon method. Further, as with all St. Lawrence dates, the use of spruce wood introduces an uncertainty due the probable driftwood origin of the spruce on now treeless St. Lawrence Island. Thus, we should probably regard the early range of the date as an unreliable estimate for the Hillside site. Ackerman (1961:4) submitted the same sample for re-dating and obtained a date of 1461±65 BP (P-325)--a date more consistent with the other dates.

The four other dates (Table II-a) for the Hillside site derive from wooden objects below the floor cobbles of OBS 1 houses 1 and 2. The dates cluster fairly well: 1641±106 BP (P-95) to 1429±121 BP (P-94) (Rainey and Ralph, 1959:368; Ralph and Ackerman, 1961:7-8) suggesting an occupation between 1853 and 1187 BP (with a two sigma range) for the Hillside site.

At Miyowagh, on ridges 1 and 2, six radiocarbon determinations reported by Ralph and Ackerman (1961: 6-7) for OBS levels range from 1700±150 BP (P-93) to 1296±108 BP (P-84)--ca. 2000-1080 BP, using a two sigma range (Table II-a). Thus, the Miyowagh occupation seems to be largely contemporaneous with rather than younger than the Hillside site. As at Hillside, the samples derive from wood and in one case, walrus hide which dates concordantly at 1380±118 BP (P-110).

Radiometric determinations for late Old Bering Sea and early Punuk at Miyowagh follow closely after the "classic" OBS period, falling ca. 1300-800 BP Wood from test pit 25 about 80-100 cm below surface directly associated with a late OBS harpoon dated to 1002±108 BP (P-85) (Ralph and Ackerman 1961:7). Punuk remains at Miyowagh date from ca. 1231±108 BP (P-88) while those at Ievogiyoq are slightly younger or contemporaneous, with dates of 1070±270 BP (P-69) and 910±145 (P-92).

The suite of 1950's dates for Old Bering Sea and Punuk cultures is internally consistent but does not provide much precision for dating particular sub-phases of the cultural sequence. Further evidence for the chronologic placement of Old Bering Sea cutlure derives from human muscle tissue from a single individual at South East Cape ^{14}C-dated at between 1545±70(SI-1656), 1613±79 (P-2090) and 1661±81 BP (I-7584) (Smith and Zimmerman, 1975:434). In general, then, the Old Bering Sea culture is contemporary with the Ipiutak culture (Larsen and Rainey, 1948) of Pt. Hope at ca. 1700-1300 BP (Gal, 1982, Larsen, 1982, written comunication) and various Birnirk sites dating to ca. 1500-1000 BP along the shores of northwest Alaska--including Kirigitavik at Cape Prince of Wales (Ralph and Ackerman, 1961:5-6) and at Cape Krusenstern (Giddings and Anderson, 1986:30).

The work of H.G. Bandi (1984) at the Old Bering Sea cemetery associated with Miyowagh further clarifies the date of the earliest Unit I at Gambell.

Evidence from Bandi's 1967-1973 Excavations near Gambell.

Hans Georg Bandi (1984) investigated cemeteries and settlements at Gambell and at several other locations on St. Lawrence Island in 1967, 1972 and 1973. Eleven graves were found at Dovelavik Bay, 6 km southeast of Gambell. Grave goods were generally meager at Dovelavik, though one grave could be assigned to the transition phase from OBS to Punuk. Diagnostic artifacts of Okvik, OBS and Punuk cultures were uncovered in the 41 graves near Kitnepaluk, 20 km south of Gambell. Many of the Kitnepaluk graves are multiple burials. Considering the 100-150 m distance from the coast, Bandi (1984) inferred an association with the long-term large settlement of Kitepaluk near the sea .

On the Gambell ridges, Bandi (1984) excavated about 100 graves, of which most were Punuk in age; but with some of Old Bering Sea age, along with several presumably older (Okvik) and some of Proto-historic age. The sample of excavated graves shows two clusters. This bimodal spatial patterning of radiocarbon dates and culturally diagnostic artifacts within the burial grounds suggests differential usa through time.

The earliest Okvik graves were eroding along the north shore of Troutman Lake--presumably on the earliest gravel ridges of the Gambell complex. However, OBS and even early Punuk graves were also encountered near the north shore of Troutman Lake, complicating the facile correlation of cultural remains with beach ridge emplacement. Burials, surely, were placed a considerable distance from the active shoreface and dates from these contexts provide poor chronological control for the deposition of individual ridges. The remaining graves were found inland east of the protohistoric settlement of Seklowaghyaget.

Though the 1984 report concentrates on the cemeteries, Bandi mentions preliminary investigations at several other settlements near Gambell. A house at the Hillside site yielded Okvik artifacts and information on the earliest culture to settle the island. He excavated a house containing Punuk artifacts at the north edge of Miyowagh and a large, probably communal, ceremonial house between the north shore of Troutman Lake and Miyowagh.

Only the burial grounds near modern Gambell (the village moved 0.5 km inland in the 1970's) were located on beach ridges. Stratigraphically, 40 to 60 cm of gravel covered the skeletal remains, though some were as shallow as 20 cm and others were as deep as 1.0 m. Only two of the 98 burials were double interrments. Bandi reports (1984) that 50% of the burials were oriented head towards the north and another 28% to the northwest or northeast, while only a few were oriented east or west. Nearly three-quarters of the burials were emplaced in the extended position.

Each burial was covered by a structure of whale and walrus bone and rocks. Some were very elaborate, while others consisted merely of two whale mandibles or ribs. Unlike their Siberian Okvik/OBS counterparts, the burials contained few grave offerings. Only 49 graves--half the graves--contained any grave goods at all. Offerings consisted of stone, ivory or bone hunting equipment and household items. The paucity of artifacts, especially of decorated items prevented the assignment of cultural affinities in all except 12 burials.

Using driftwood or whale bone, Bandi (1984:61) dated twenty five (n=25) graves using the ^{14}C method (Table II-aa). In only six cases both driftwood and whale bone dates were obtained from the same grave; the whale bones yielded dates about 400 years older than the wood dates, with a range of between 120-640 yrs (Table II-aa). Bandi (1984:61) explains this discrepancy by referring to the reservoir effect involving the long residence time of CO_2 , and hence of ^{14}C , in the ocean, relative to the atmosphere.

Since sea mammals ultimately obtain carbon from marine organisms lower in ^{14}C concentration, sea mammal derived dates are generally too old (Arundale, 1981). The same phenomenon is well-known from Scandinavia and world wide (Stuiver et al., 1986) and may allow us to add 400 years to the whale bone dates. Bandi's finding may be taken as the current best approximation for the marine mammal old carbon effect in the western Arctic and may assist Alaskan archaeologists in correcting sea mammal biased dates from throughout the region.

Only six graves of the 98 Gambell graves excavated by Bandi could be dated *both* by diagnostic artifacts and ^{14}C (Table II-aa). Correcting for the old carbon effect (subtracting 400 yrs), Bandi's dates provide a slightly earlier date for Okvik (ca. 2050±40) coupled with one just as young as the 1950's series--1620-1280 BP The dating of Okvik ca. 2000 BP may prove a reliable chronological assignment considering the few reported Soviet dates.[1] With only these few dates, however, it is advisable to suggest that later peoples may have curated older artifacts thus accounting for the difference in age. The surprising young OBS date of ca. 990-710 BP may be explained in the same manner. Dates on the transition from OBS to Punuk seem better approximated by Bandi's dates--1410-1130 BP with early Punuk falling at 1270-990 BP In summary, then, the result of Bandi's more extensive 1970's dating program confirms the solid carbon derived radiocarbon chronology of the 1950's.

Internal Stratigraphy at Miyowagh

Collins (1937: 56ff and notes on plates) recorded artifact provenience with surprising attention to stratigraphic position and on occasion provides some stratigraphic descriptions. In describing the Miyowagh stratigraphy, Collins (1937: 57-58) observes that the midden is "compact and unstratified" and

> occasionally a thin layer of mussel shells or a mass of bones would stand out distinctly and along the western periphery, lenses of midden material were sometimes separated by masses of gravel...as a rule no stratification [was observed] in the usual sense the bones, artifacts and rejectage being a relatively homogeneous mass, held together in a solid matrix of permanently frozen, rich, black soil.

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[1] Dikov (1977:243) reports several dates for three small "Old Bering Sea" sites NW of Uelen on the Chukotsk Peninsula: 2022 ±100 (MAG-104), 1990±190 (MAG-233) and 1750 ±100 (MAG-354) B.P.

In much of the Miyowagh mound, a clear stratigraphic separation is documented for Old Bering Sea and Punuk levels. About 40-50 cm of gravel overtops the entire occupational surface in the NW. The total depth excavated at Miyowagh varies from about 1.2 in the NW to 2.5 m in the SE, with the NW portion being drier and better drained but with preservation being better in the wetter SE area only "50 yds" (ca. 50 m) from the adjacent, upsloping Hillside site area. In stratified contexts, Punuk culture remains generally lie 50-100 cm above OBS culture levels. For example, at Cut 3 (NW), 40 cm of gravel tops the Punuk levels at 51-61 cmbs, and the OBS levels at 137-152 cmbs. The stratigraphic levels associated with Punuk or OBS remains are not consistent across the Miyowagh mound and some mixing of OBS with Punuk does occur, especially in the SE portion of the mound. At Cut 7 (SE) the archaeological horizons are thicker with Punuk extending 51-157 cmbs and OBS 170-243 cmbs. Some of the excavation units of the SE portion of Miyowagh contain only discrete subsurface OBS components (cuts 23-25).

In summary, we interpret Collins' descriptions of the internal beach ridge stratigraphy at Miyowagh as indicating that OBS and Punuk were separated by several cm of storm-deposited gravel and shell. These layers appear to reflect heightened storm activity that occurred after the Old Bering Sea occupation and prior to the Punuk occupation, thus probably ca. 1200-1000 BP.

Correlations between the Gambell Ridges of Bering Sea and Kotzebue Sound Ridges

Collins' and Bandi's series of 43 radiocarbon dates for the sites on Gambell Unit I record an occupation from ca. 1700 to 1000 BP. Dates from both cemetery and Ievogiyoq excavations establish an upper limiting age of 1130±70 BP (B-3210) to 910±145 BP (P-92) for termination of the Punuk occupation of Unit I. At this time, 1270-990 BP, a series of intense storms resulted in massive erosion at Gambell, producing the Unit II disconformity. Correlations with Kotzebue Sound suggests that the succeeding Unit III ridges were built during an interval of less stormy conditions between 1000 yrs. BP to 400 BP. During Unit IV times climate again shifted to a predominantly erosive regime.

The Gambell depositional history corresponds well with the record from Kotzebue Sound. The erosional disconformity of Gambell's Unit II occurring at ca.

1270-990 BP correlates with a similar well-dated shift in sedimentation regime at Cape Espenberg (Mason, 1987; 1988a; 1988b) and Cape Krusenstern (Giddings and Anderson, 1986; Mason, 1988a). On the sand spit of Cape Espenberg, an abrupt change is noted at ca. 1200-900 BP marked by the development of transgressive dune ridges. Recent excavations at Cape Espenberg (Harritt, 1989, Mason this volume, Ch. 2) has produced a series of ^{14}C dates, providing a refined definition of the timing of the depositional shift before 800 BP An erosional disconformity cutting across the gravel ridges of Cape Krusenstern also marks the commencement of the early Thule occupation--ca. 1270-780 BP (Giddings and Anderson, 1986:30).

The fact that the Gambell sequence correlates well with the Kotzebue Sound sequence should, of course, come as no surprise since both areas are affected by the transit of weather systems from the North Pacific into the Chukchi Sea. Powerful storm systems during the fall generate winds capable of producing elevated seas and high waves (Wise et al. ,1981).

Geoarchaeological Problems at Cape Krusenstern

The Mobility of Gravel and the Formation of Beach Ridges

During the summer of 1988 the shores of the Chukchi Sea were subjected to numerous storms which produced high waves and elevated sea levels. The rapidity of beach transformation was witnessed by the NPS Cape Krusenstern survey crew. The Krusenstern coast witnessed both erosion and ridge deposition during surprisingly short intervals. NPS field crew members J. W. Jordan and S. L. Ludwig (1988, unpublished data) photogrammetrically documented beach changes of several decimeters within periods of only 6 to 12 hours. On the south shore of the Cape Krusenstern Monument a transgressive wedge of gravel 0.5 m thick covered the crest of a berm seaward of an erosion monitoring stake that had been emplaced by Jordan a week before the storm. An insubstantial tripod of branches topping the monitor stake remained intact, though buried, providing an indication of how rapidly a human occupation site might have been buried during the construction of a beach ridge.

The rapidity and unevenness of such transformations do not surprise the coastal geomorphologist since gravel deposits are well-known for their ability to be shaped during storms. Seventy years ago, Johnson (1919) cautioned against using any particular gravel ridge to infer a *particular* storm event or sea level. However, this lesson has yet to be appreciated by many Arctic archaeologists. A gravel beach ridge should be taken as the composite product of numerous storm events. At Gambell gravel ridges Collins' excavations in gravel beach ridges did possess a very subtle but discernible internal stratigraphy and Mason (1987b) observed numerous discrete grass laminae separating gravel beds representing seaparate sedimentation events in gravel ridges at Choris Peninsula. Comparable internal stratigraphy has not been reported for Cape Krusenstern--despite the fact that site loci such as the Old Whaling houses were transgressed by more than *one meter* of gravel, presumably deposited by marine agencies. The mechanism for such rapid site burial probably involved large scale storms similar to those observed by the NPS crew during 1988.

Along the northern portion of the Krusenstern complex, the eight shoreward ridges (n=8) actually coalesce into a single high ridge, which, in turn, itself transgresses the western Thule ridge 9 to the landward (Giddings and Anderson, 1986:41).

The Dating of the Cape Krusenstern Beach Ridge Complex

As for the chronology of the 114 Cape Krusenstern beach ridges, the suite of dates (n=33) at first appears substantial (Giddings and Anderson, 1986:30). On closer inspection, however, we find that more than half of the dates (n=19) derive from a single ridge--the Old Whaling ridge 53 (Table II-1). The remaining thirteen radiocarbon dates are distributed on *only* seven ridges--and five of these are from the prominent Ipiutak ridge 35. Thus, only *two* of the 114 ridges have more than two radiocarbon determinations.

Of the two seemingly well-dated ridges, the situation of the Old Whaling ridge is symptomatic--the date range of the 19 determinations[2] shows a trimodal tendency, as Anderson observed (Giddings and Anderson 1986:33). The earliest aged set of dates falls ca. 3625±24 BP (according to Stuckenrath et al., 1966:366, but listed as 3522 ±59 BP by Anderson[3] in Giddings and Anderson, 1986:33) is discarded by Anderson due to

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2 In addition to the 18 dates listed by Giddings and Anderson (1986:30), Gfeller et al. (1961:30) report a date of 2530±130 B.P. for Old Whaling house 21.

3Anderson (1986 in Giddings and Anderson 1986:32ff) rejects three dates in averaging his list--the two young dates from House 21 and only one of the too "old" dates from likely old carbon fractionation factors since the "charcoal" chosen for dating probably is charred sea mammal remains. A substantially younger "tight-clustering" set of dates averaging at 2848±23 BP derives from wall posts, "all slender (ca. 5 cm diam) saplings presumed to have been cut locally" (Stuckenrath et al. 1966:366). Mixed samples with both wood and charred sea mammal remains show average values at 3090±60 BP, in between the extreme values. Hence, it seems advisable to accept only the wood dates (n=7) and place the age of ridge 53 at about 2900-2800 BP, though Anderson prefers to use his averaged date of 3170±59 BP (which subtracts 10 per cent from sea mammal biased dates).

The corpus of Ipiutak dates also reveals several inconsistencies--especially in the case of a single house (H-30) on ridge 35 which yielded dates separated by about 500 years--1950 versus 1500 BP (Giddings and Anderson, 1986:30,126-127) The younger date of 1499±57 BP (P-597a) seems more acceptable since it derives from charred timber in contrast to the older date of 1944±52 BP (P-595a) on "charcoal," which possibly is sea mammal contaminated. The wide spread of dates for the Ipiutak ridge ca. 1800 to 1400 BP suggests that ridge 35 stood near the shore for a long period of time--possibly during a comparatively less stormy interval. Subsequent Ipiutak sites on ridges 29 and 30 are only slightly younger in age, 1500-1150 BP, and lead to the inference of rapid progradation between early and later Ipiutak times--a circumstance similar to that of Cape Espenberg (Mason, 1988b).

The Old Whaling and Ipiutak date series also provides additional data to calibrate sea mammal biased dates since paired wood and sea mammal samples at Krusenstern are derived from the same discrete occupations in Houses 21, 23 or 24. However, the difference between dated pairs at Krusenstern is greater than that of St. Lawrence Island dates (see above). At Krusenstern, the mean difference between wood and sea mammal biased dates is 650 years (with a range of 441-819 yrs). If we combine the two sets of data (n=11) from Krusenstern and St. Lawrence, we obtain a mean of about 503 yrs (range of between 120 to 819 yrs) for the biasing effect of sea mammal derived dates. Though both regions may be different in regard to the residence time of CO_2 in deep water, the large range of the values cautions against using our estimate of 400-500 years as anything more than a regional yardstick for the 'old carbon" effect.

House 24 The dismissal of the "young" dates seems ill-advised since the sizable sigma values (130 and 150 yrs) would place them well within other age assignments using a two sigma range.

In summation, it is clear that a principal research need for Cape Krusenstern involves the collection of additional radiocarbon samples.

The Numbering of the Ridges at Cape Krusenstern

Nearly every arctic archaeologist can probably recall the number of beach ridges at Cape Krusenstern. This number--114--has taken on almost a ritual significance. However, even with the publication of the recent monograph, it remains nearly impossible to pinpoint the location of particular ridges within the system or to explain the procedures followed in numbering ridges. Giddings (1963: 2) did provide a few hints about his methods in a rather brief article:

> The beach numbers refer to 114 identified beaches in series at the Cape [Krusenstern] on most of which were localized archaeological sites that range in time from No. 1, which is the current ocean front where recent Eskimos have camped to No. 105 which is the oldest which artifacts have yet been recovered, and on to No.114, presumably, the first beach to form after sea level reached approximately its present height following Wisconsin glaciation. Because of unconformities where segments of old beaches were erased at several times, *sites may not always be assigned a precise beach number* [our italics].

As is well known then, the ridges are numbered with increasing distance from the sea. But, as Giddings admits not all ridges are continuous across the entire complex--as Giddings (1962:35), observed "all counts are necessarily approximate" Thus, many very short, discrete ridges are probably included in the 114 count. Why is this important?

The often repeated figure of 114 ridges gives the false impression of a relentless, unceasing succession of beaches piled one in front of another. This is not the case. Several notable disconformities occur within the complex as Moore and Giddings (1961) pointed out. The three most important disconformities occur at archaeologically quite significant junctures:

(IV/VI) after Old Whaling (ridge 53);
(II/III/IV) before unit II Ipiutak (ridge 35);
and (I/II) after western Thule (ridge 9).

As is well known, these disconformities define the six depositional units of the Cape Krusenstern complex (Fig. 6.2) (Giddings and Anderson, 1986:24).

The disconformities in depositional regime led Moore and Giddings (1961, Giddings 1966) to define the history of the Krusenstern complex in terms of shift in onshore wind directions. A crucial nexus for this inference lies in the northwest part of the complex. For much of the rest of the Cape Krusenstern complex, several often conflicting demarcations have been proposed: first by geologist George Moore (cf. Hopkins 1986: Fig. 2), then by Giddings (1966: Fig. 3) and lastly by Greg Zimmerman (1981), who did a photo interpretation of cultural features at Cape Krusenstern.

While agreeing for the most part about the western portion of the Krusenstern complex, Mason found, inspecting aerial photos, that none of these maps accurately defines the eastern portion of the complex In fact, it seems that the mapping of Krusenstern proceeded west to east. This procedure has led to the mapping confusion. It is preferrable to start mapping **east to west** since nearly all the ridges recurve toward the eastern limit of the complex due to the longstanding influence of a tidal channel at that point, Mason (1988c) produced yet another map of the Krusenstern succession (Fig. 6.3). This subdivision differs in the eastern portion of the complex: the two units, in Roman numerals, **IV** and **V** of Giddings (1966) is subdivided into **three** units, oldest to youngest, using arabic numbers: **3, 4** and **5**.

The principal bone of contention at Krusenstern lies in the erosional disconformity associated with Old Whaling, ridge 53, the disconformable contact between Giddings' units IV and VI. Extensive erosion must post-date the Old Whaling settlement. Ridge 53 continues about 2-3 km eastward and suddenly splays into several ridge fragments. Mason uses these splays to define an additional unit 3. This unit must be erosional in nature. After Old Whaling times, the focus of deposition shifted abruptly and resulted in the displacement of gravels eastward. Hence, portions of ridges included in Mason's unit 4 and 5 postdate Old Whaling ridge 53. To examine the significance of these arcane sedimentological matters archaeologically, let us turn to the problem of early Choris.

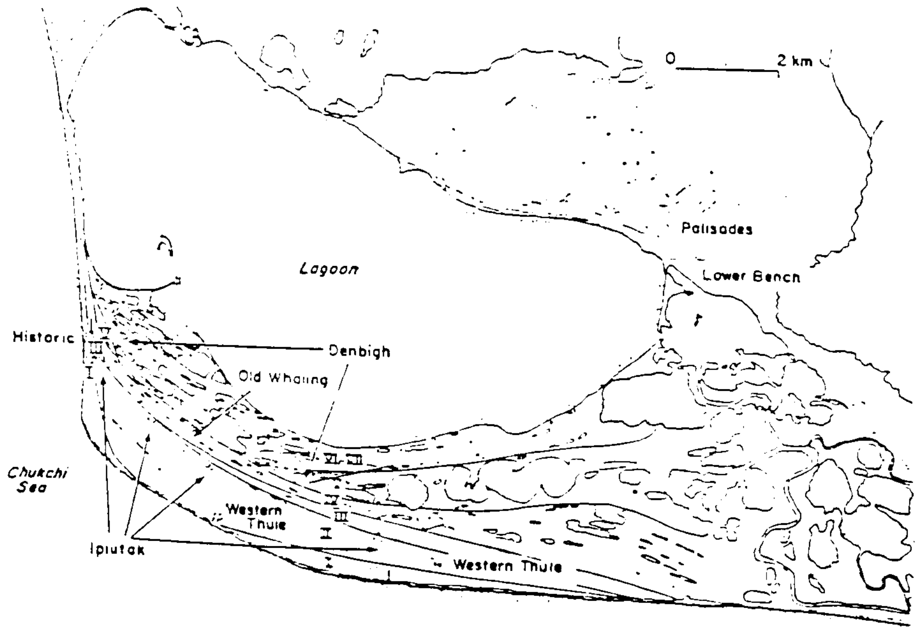

Fig. 6.2. Depositional units at Cape Krusenstern as defined by Giddings (1966) on the basis of major disconformities in ridge alignment. Giddings appears to have worked west to east, neglecting the intersection of ridges with the tidal channel to the east. Courtesy of AAAS, Science.

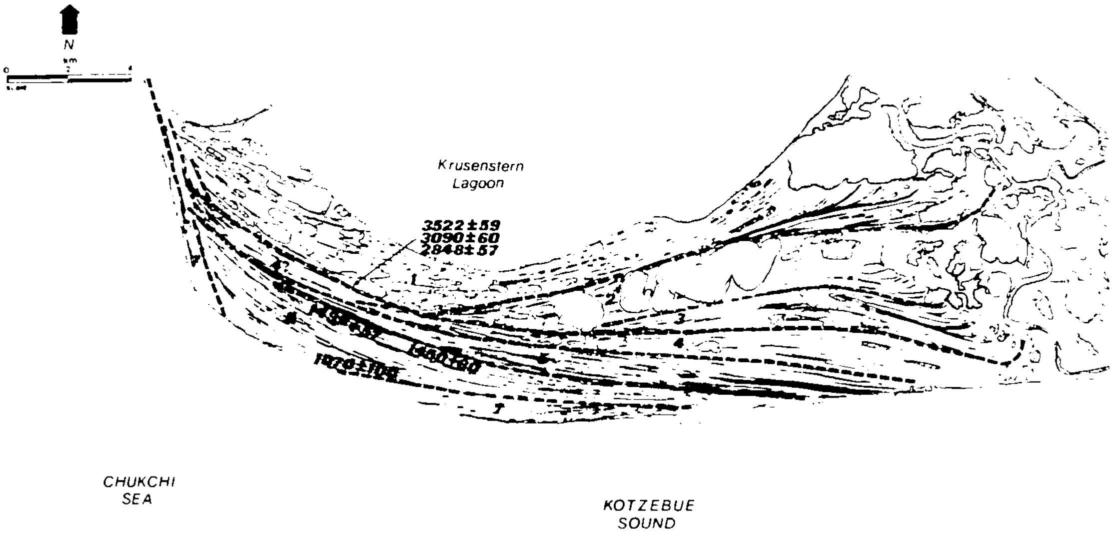

Fig. 6.3. Depositional units at Cape Krusenstern as defined by Mason (1988c). The configuration of the former tidal channel to the east of the main complex was used as a datum for delineating depositional units. As a result, the numbering of depositional units differs from that of Giddings in Fig. 6.2.

Applying Geoarchaeological Reasoning to Beach Ridge Archaeology

The Choris Problem: Dating by Ridge Position.

A glance at Giddings and Anderson's (1986:31) chronological table for Kotzebue Sound reveals that a great reliance is placed on ridge position to date about half of the sequence. Further, as is well known, most of the chronological referents are provided by the inland Onion Portage site (Anderson, 1988). However, to use ridge position as a chronological placement, we must consider geomorphic processes. As an example, consider the placement of early Choris, a post-Denbigh transition culture, located on Unit V, listed as ridges 54-78.

As mentioned above, the delineation of ridges at Cape Krusenstern is far from clear since sites are not located cartographically in Giddings and Anderson (1986); only ridge designations are given. It is unclear where the ridges 54-78 actually lie. Since unit V widens to the east, more ridge fragments may be enumerated in the farthest east portions of the complex. Therefore, most of these 54-78 ridges must lie at the eastern margin. Most likely, then, many of these ridges lie in the erosional units identified by Mason.

If early Choris remains lie on the erosional ridges that post date Old Whaling then, clearly, the date of the artifacts falls after 2800 BP and is in line with classic Choris of the Choris Peninsula, rather securely dated to ca. 2800-2400 BP However, some of the early Choris ridges do proably lie in previously defined older portions of the 54-78 ridges.

The only way to clear up this unruly state of affairs involves undertaking more precise mapping of the Krusenstern ridges and efforts to obtain datable organics. To do beach ridge archaeology, investigations must center on the geomorphic processes on the beach ridges themselves.

Conclusions

In closing, we would like to stress that despite its nearly 100 yr history in Alaska, beach ridge archaeology is far from a closed book. Too often it seems, Alaskan archaeologists have curtailed discussion or criticism of the subject out of respect for the legendary J. Louis Giddings or interest in beach ridges lapsed with his departure. Regrettably, Giddings spent only four seasons from 1958-1962 at the Krusenstern ridges before his death in 1964. Though Giddings accomplished an incredible amount in that short time, much remains to be done, as he would likely have been the first to admit. It is time now to engage in a critical review of beach ridge archaeology and plan for the future.

As we found in looking at the St. Lawrence Island materials, it is possible to use archaeological data in a manner unintended by the original investigators and to integrate the depositional history of Gambell into the Kotzebue Sound sequence.

To summarize, we find:

(1) the principal occupations at Gambell fall at ca. 2000-1000 BP, during a time of comparatively less stormy conditions as attested from the similar depositional histories of Cape Espenberg and Krusenstern;

(2) the 400-500 year correction factor obtained from whalebone/wood at Gambell and Krusenstern can probably be applied to dates on sea mammal and marine mollusk dates throughout western Alaska;

(3) the dating of Cape Krusenstern ridge complex is still sketchy and remains controversial, especially in reference to the Old Whaling disconformity and subsequent events. More attention is needed in its dating and depositional history;

(4) a great need exists for the investigation of beach ridge micro-stratigraphy so that the history of storm events can be tied to the archaeological record.

Table I

Fetch Distances across the Chukchi Sea.

Location	Direction	Distance (km) (Open Water)
Wrangel Island (USSR) to Shishmaref	NW/SE	Max. Ice: 530 Min. Ice: 1125
Pt. Hope to Kitluk River	N/S	220
East Cape (USSR) to Shishmaref	W/E	185
Mys Schmida (USSR) to Choris Peninsula	WNW to SSE	780
St. Lawrence to Pt. Hope	SW/NE	560
Chaplino (USSR) to Cape Krusenstern	SSW to NNE	500

Table II

Radiocarbon Samples from West and Northwest Alaska Beach Ridges and Chenier ridges, from the Yukon Delta to Pt. Barrow, including St. Lawrence Island. List follows south to north gradient. Samples are from both archaeological and geological (B,C, F and K) contexts. Asterisks (*) denote calibrated radiocarbon ages with multiple intercepts, the mean of these is presented here.

Table II (a)

St. Lawrence Island
O=Okvik; OBS=Old Bering Sea, P=Punuk, M=Miyowagh, I=Ievoghiq

Lab. No.	Age ^{14}C YrsBP	Calibrated BP	Ages BC/AD	Site/Period	Material	Context (m bs)
Gambell series: 1950's samples--collected in 1930's (n=15)						
P-92	910±145	835*	1115 AD	I, P	Wooden obj.	1.32
P-69	1070±210	967	983 AD	I, P	Wood Dish	1.32
P-83	1013±111	940*	1010 AD	M, early P	Wood shaft	1.35
P-88	1231±108	1161*	789 AD	M, early P	Lg. Log	2.5
P-85	1002±108	940*	1010 AD	M, late OBS	Wood	0.8-1
P-80	1398±116	1307	643 AD	M, OBS	Wood	0.8
P-93	1700±150	1625*	325 AD	M,OBS	Wood obj.	0.94
P-71	1630±230	1536	414 AD	M, OBS	Wood object	1.32
P-84	1296±108	1266	684 AD	M, OBS	Roof beam	1.4-1.6
P-110	1380±118	1302	648 AD	M, OBS	Walrus, Hse. 4	0.81.75
P-95	1641±106	1540	410 AD	H, OBS	Wood obj. Hse. 1	
P-70	1420±230	1310	640 AD	H, Okvik	Wood obj. Hse. 2	
P-94	1429±121	1311	639 AD	H, Okvik	Wood obj. Hse. 2	
P-325	1461±65	1350	600 AD	H, Okvik	Spruce log Okv. hse.	
C-505	2258±230	2331	382 BC	H, Okvik	Spruce log Okv. hse.	

Table II (aa)

Gambell Cemetery, south of Miyohaq, excavations in 1967-73 by Bandi (1984)

Graves containing diagnostic artifacts					
B-3205	1410±60	1308	642 AD	Okvik	Wood
B-2877	2450±40	2544*	594 BC	Okvik	Whale Bone
B-2434	850±70'	750*	1200 AD	OBS	Wood
B-244	1400±90'	1307	643 AD	OBS	Whale Bone
B-2852	1270±70"	724*	1226 AD	OBS/early P	Wood
B-2853	1760±50"	1658*	292 AD	OBS/early P	Whale Bone
B-3210	1130±70	1031*	919 AD	early P	Wood
B-2876	1550±60	1449*	501 AD	early P	Whale Bone

'from grave 24, " fr. grave 42/1

Table II (aa) continued
Other cemetery dates (Bandi 1984:61)
Dates in both columns derive from the same grave

Wood				Whalebone			
Lab. No	^{14}C Yrs BP	Calibrated BP	AD/BC	Lab. No	^{14}C Yrs BP	Calibrated BP	BC/AD
B-3204	460±70	515	1435 AD	B-2433	1100±70	1016*	934 AD
				B-2432	650±80	615*	1336 AD
B-894	780±50	691	1259 AD				
B-890	840±70	738	1212 AD				
B-3209	880±80	777*	1173 AD				
B-2862	940±60	841*	1109 AD	B-2870	1340±60	1285	665 AD
B-2856	940±70	841*	1109 AD				
B-2860	950±90	842*	1108 AD				
B-2855	970±50	925	1025 AD				
B-2850	980±60	927	1023 AD				
B-3207	990±70	929	1021 AD				
B-2858	990±70	929	1021 AD	B-2857	1110±60	1006	944 AD
B-3208	1000±70	940*	1010 AD				
				B-2441	1010±60	940	1010 AD
B-2431	1040±90	955	995 AD				
B-3213	1040±70	955	995 AD	B-3218	1070±70	967	983 AD
B-3214	1150±80	1061	889 AD				
B-3219	1160±80	1064	886 AD				
B-3211	1260±70	1216*	734 AD				
B-3206	1310±60	1273	677 AD				
B-2859	1530±80	1411	539 AD	B-2875	1720±50	1657	293 AD

Table II (aaa)

Non-beach ridge samples from St. Lawrence Island
Kialegak (SE Cape) 1970's samples (n=3), Smith and Zimmerman 1977

Lab. . No	^{14}C Yrs. BP	Calibrated BP	BC/AD	Site/Period	Material
P-2090	1613±79	1524	426 AD	OBS	Human muscle
I-7584	1661±81	1557	393 AD	OBS	Human muscle
SI-1656	1545±70	1415	535 AD	OBS	Human muscle

Table II (b)

Yukon Delta–Geologic Dates from Chenier Ridges (Robinson and Trimble 1981, 1983, collected by William Dupre in 1976-77)

Lab. No.	Age ^{14}C Yrs. BP	Calibrated Age BP	BC/AD	Locality	Material Context (m bs)
(USGS-48)	820±90	731	1219 AD	Modern Delta	Basal peat, 1.5 m below surface
(USGS-212)	1430±50	1311	639 AD	Sheldon Pt	Wood in Peat, youngest chenier
(USGS-225)	1550±80	1449	501 AD	Black River	Basal Peat, 1.7 m below surface,dates truncation of cheniers
(USGS-218)	1800±90	1750	200 AD	Kwikluak Pass	Basal peat, 1.5 m below surface
(USGS-53)	1890±90	1843	107 AD	Black River	Basal peat, Middle of Cheniers
(USGS-214)	2420±80	2403	453 BC	Kwikluak Pass	Wood, one of oldest cheniers
(USGS--226)	2570±70	2741	792 BC	Eleutak	Basal peat, 0.8 m below surface one of oldest cheniers

Table II (c)

Norton Sound–Box cores–Submarine Geologic Samples (collected by C. H. Nelson in 1977, reported in Robinson and Trimble 1981, 1983)

Lab. No.	Age ^{14}C Yrs. B.P.	Calibrated Age BP	BC/AD	Locality (mbs)	Material, Context
(USGS-183)	2090±120	2089	139 BC	45 km fr. Yukon Delta	Wood from top 15 cm of box core 18 m below MSL, dates storm sand layer
(USGS-353)	3070±40	3293	1345 BC	Norton Sound 30 km W. of Yukon Delta	Peat Laminae 0.03 to 0.09 m below top of box core, 10 m below MSL dates storm surge nr. delta
(USGS-354)	3590±140	3910	1960 BC	Norton Sound: 40 km NW, Yukon Delta	Peat layers, 0.13 to 0.16 m below top of boxcore 10 m below MSL

Table II (d)

Safety Sound (Bockstoce 1979, Dumond 1984, converted from the original calculations, using the 5730 yr half life, shown on far right)

Lab. No.	Yrs ^{14}C BP	Calibrated Age BP	Calibrated Age BC/AD	Culture	Material Context	5730 half-life
I-6065	2216±97	2212*	262 BC	Norton	hearth charcoal	2280±97
I-5983	2047±79	2030*	80 BC	Norton	hearth charcoal	2107±79
I-5379	1973±99	1911*	39 AD	Norton	hearth charcoal	2030±99
I-5376	1662±95	1557	393 AD	late Norton	hearth charcoal	1710±95
I-5378	1719±181	1672	278 AD	late Norton	hearth charcoal	1769±181
I-5380	1593±89	1473*	477 AD	late Norton	hearth charcoal	1639±89
I-5377	1374±92	1300	650 AD	Birnirk	hearth charcoal	1416±92
I-5982	1243±74	1177	773 AD	Birnirk	hearth charcoal	1281±74
I-5987	294±88	364	1587 AD	Thule	----	303±88

Table II (e)

Wales: Kugzruk (K) and Aguulaak (A) in Lopp Lagoon (Giddings and Anderson 1986:30, Stuckenrath et al. 1966)

Lab. No.	Age ^{14}C Yrs BP	Calibrated Age (BP)	Calibrated Age BC/AD	Culture	Material
P-598	2566±53	2740	791 BC	Norton (K)	Charcoal & Sand
P-592	2583±60	2743	794 BC	Norton (K)	Charcoal & Sand
P-629	2306±38	2343	394 BC	Norton (K)	Wood
P-599a	2402±43	2403	453 BC	Norton (A)	Charcoal

Table II (f)

Shishmaref Barrier Islands
Kividluk – Geologic Samples (Jordan 1989, 1990)

Lab. No.	^{14}C Yrs. BP	Calibrated Age BP	BC/AD	Material
ß-28182	320±60	378	1572* AD	Grass
ß-33553	460±80	515	1435 AD	Peat
ß-28184	520±70	535	1415 AD	Grass
ß-33552	640±70	599	1351 AD	Peat
ß-33551	980±70	927	1023 AD	Peat
ß-28181	1070±80	967	983 AD	Grass
ß-28183	1550±70	1449	501* AD	Grass

Archaeological dates from Kividluk (KTZ-009)
Schaaf 1988a: 459-461, Jordan 1990, pers. comm.)

ß-17973	170±70	151	1799 AD	Charcoal, 107-115 cm bs
ß-17958	290±70	310	1640AD	Charcoal, 55 cm bs
ß-34772*	470±70	518	1432 AD	Charred Wood, Charcoal 80 cm bs

Table II (g)

Cape Espenberg

Archeological Samples (cf. Schaaf 1988, Harritt 1989, 1990)
All samples are Charcoal, except where noted.

Laboratory Number	^{14}C Date (yrs BP)	Calibrated Ages BP	BC/AD	Site, Ridge No.		Context (cm bs)
Unit IV						
ß-17967	210±60		1663 AD	KTZ-101 E-2c		80
ß-28196	100±90	144*	1806 AD	KTZ-101,	E2c ridge	90
ß-28019	260±50	302	1648 AD	"	"	94
ß-28197	200±70	204*	1746 AD	"	"	72
ß-28021	290±90	310	1640 AD	"	"	114
ß-28022	240±70	297	1653 AD	"	"	110-130
Average of the series: (excl. the first date)	247±33		1656 AD			

Table II (g) Cape Espenberg (continued)

Laboratory Number	^{14}C Date yrs BP	Calibrated Age BP	BC/AD	Site, Ridge No.	Context (cm bs)
ß-17965	~~590±90~~	~~599~~*	1351**AD	KTZ-69 E-3b	28 house entry
ß-17963	310±80	379*	1571**AD	KTZ-88 E-4	46 floor, Fea. 1
ß-28013	730±100	672	1278 AD	KTZ-88/ E-4	77
ß-28195	300±50	380*	1570 AD	"	150
ß-28006	700±70	670	1280 AD	KTZ-87/E-5	68
ß-28008	790±70	693	1257 AD	"	86
ß-28009	720±70	671	1279 AD	"	86
ß-28011	730±90	672	1278 AD	"	91
ß-28013	730±100	672	1278 AD	"	77
Average of 5:	735±37		1277 AD	"	
ß-28194	440±60	511	1439 AD	"	73
ß-28007	1020±120	951	999 AD	"	86
Ridges A-3 and C-2 are correlative with E-3b/4					
ß-17959	430±80	505	1445 AD	KTZ-148 A-3	29-32 in cutbank, Fea. 4
ß-17970	500±80	528	1422 AD	KTZ-130 C-2	95 exposed hearth charcoal & uncarbonized organics
Ridge C4/5 correlative with E-5/6					
ß-17969	1010±90	935	1015 AD	KTZ-115 C-4/5	exhumed paleosol charcoal, wood, organics
Unit III (Harritt 1989)					
ß-28024	1300±70	1268	682 AD	KTZ-157 E-8	65
ß-28198	1360±90	1293	657 AD	KTZ-157 E-8	45
ß-28022	1410±60	1308	642 AD	KTZ-157 E-8	58
Weighted Average:	1358 ±41		657 AD		

Table II (g) Cape Espenberg (continued)

Laboratory Number	^{14}C Date (yrs BP)	Calibrated Age BP	BC/AD	Site, Ridge No.	Context (cm bs)
Unit II					
Ridge B-9 is correlative with C-10 and E-14.					
ß-17972	2850 ± 70	2957	1008 BC	KTZ-133 B-9	Surface Cemented Sand: Sea mammal oils
ß-33759	2790±80			KTZ-127 C-10	2.5 m below surface within paleosol
ß-33760	2530±130			KTZ-127 C-10	2.5 m below surface within paleosol
Weighted average of 2:	2719 ± 68	2817*	869 BC		
ß-17961	2660 ± 110	2767	818 BC	KTZ-79 E-14	59-64 within paleosol
ß-17962	2340 ± 80	2348	399 BC	KTZ-79 E-14	75-78 within paleosol
ß-17966	2500 ± 90	2616	667 BC	KTZ-98 E-14	38-42
ß-17968	2285 ± 90	2339	390 BC	KTZ-108 E-14	82 charcoal Fea. 8

Table II (g) Cape Espenberg (continued)

Laboratory Number	^{14}C Date (yrs BP)	Calibrated Age BP	BC/AD	Site, Ridge No.	Context (cm bs)
Unit I					
Ridge C-12ab correlative with E-20abc					
ß-19643	3570±100	3854	1904 BC	KTZ-96 E-18	12-21 buried hearth
ß-33758	3750±80	4115*	868 BC	KTZ-122 C-12b	35 cm bs paleosol
(b) Geological Samples					
Unit IV					
ß-20028	1520±60	840	1110 AD	E-4	Surface Shell
ß-23169	820±70	------------------		E-5	Surface Shell
ß-23172	500±60	528	1422 AD	A-5	125 Grasses at cutbank, exposed by wave action
Unit II					
ß-23171	1640±80	1539	411 AD	E-14	120-125 Soil matrix, paleosol organics
Unit I					
ß-23170	3700±90	4027*	2077* BC	E-20	50 Grasses, soil paleosol matrix

Table II (h)

Choris Peninsula
(Giddings and Anderson 1986:30, Ralph and Ackerman 1961, Stuckenrath et al. 1966)

Lab. No.	^{14}C Yrs. BP	Calibrated BP	Calibrated BC/AD	Material	Ridge, Unit
P-96	2635±125	2753	804 BC	Wood	A-8, Unit II
P-175	2244±133	2248	298 BC	Antler	A-8, Unit II
P-203	2646±177	2756	807 BC	Charcoal	A-8, Unit II
P-611	2190±51	2226	276 BC	Charcoal	A-5, Unit III

Table II (i)

Cape Krusenstern (Giddings and Anderson 1986, Gfeller et al. 1961 and other references cited above)

Lab. No.	^{14}C Yrs	Calibrated BP	Calibrated BC/AD	Archaeo. Culture/Feature	Ridge	Material Location
K-837	1180±110	1130*	820 AD	Kotzebue H-50	1-9 merged at North end	Charcl
K-850	1000±110	940*	1010 AD	W. Thule H-410		Charcl
B-281	770±120	689	1261 AD	W.Thule H-25	10	Food remains
K-817	1070±100	967	983 AD	W.Thule H-6	11	Charcl
P-613	906±56	835*	1115 AD	W.Thule/Birnirk B-6	[Unit IIIa]**	Skin, Wood
K-851	1180±110	1130*	820 AD	Birnirk H-32	9 over 8	Charcl/bone
K-816	1100±100	1016*	934 AD	Birnirk H-33	9 over 8	Charcl
B-280	1250±100	1197*	753 AD	Ipiutak H-18	29	Charcl
P-612	1441±58	1326*	624 AD	Ipiutak H-17	30	Charcl
B-266	1450±80	1327*	623 AD	Ipiutak H17	35	Charcl
P-225	1651±130	1543	407 AD	Ipiutak H-11	35	Charcl
P-596A	1730±61	1659*	291 AD	Ipiutak H-60	35	Charcl/Wd.
P-595A	1944±50	1908*	42 AD	Ipiutak H-30	35	"Charcl"
P-597A	1499±57	1391	559 AD	Ipiutak H-30	35	Charcl
P-627	2775±50	2901*	951 BC	Old Whaling H-20	53	Wood
B-267A	2470±150	2546*	596 BC	Old Whaling H-21	53	Char'l
B-267B	2530±130	2650*	700 BC	Old Whaling H-21	53	Wood
P-402	3082±63	3297*	1347 BC	Old Whaling H-21	53	Char Mtl&Wd
P-626	3647±53	3950*	2000 BC	Old Whaling H-22	53	Char'd Mat'l
P-405	3583±65	3927*	1977 BC	Old Whaling H-22	53	Char'd Mat'l

Table II (i) (continued)

Cape Krusenstern (Giddings and Anderson 1986, Gfeller et al. 1961 and other references cited above)

Lab. No.	^{14}C Yrs	Calibrated BP	Calibrated BC/AD	Archaeo. Culture/Feature	Ridge	Material Location
P-624	3571±66	3854*	1904 BC	Old Whaling H-23	53	Char'd Mat'l
P-401	3630±53	3948*	1998 BC	Old Whaling H-23	53	Char'l
P-623a	3291±65	3515*	1565 BC	Old Whaling H-23	53	Char'd Mat'l
P-403	2850±63	2984*	1034 BC	Old Whaling H-23	53	Wood
P-621	2859±63	2984*	1034 BC	Old Whaling H-23	53	Wood
P-615A	2907±55	3079*	1129 BC	Old Whaling H-23	53	Wood
P-400	3678±63	4039*	2089 BC	Old Whaling H-24	53	Char'd Mat'l
P-614	3655±58	4033*	2083 BC	Old Whaling H-24	53	Char'd Mat'l
P-617	2989±50	3166*	1216 BC	Old Whaling H-24	53	Char Mtl & Wd
P-618	2865±49	2997*	1047 BC	Old Whaling H-24	53	Wood
P-404	2829±63	2940*	990 BC	Old Whaling H-24	53	Wood
P-619	3024±51	3253*	1303 BC	Old Whaling H-205	53	Char'd Mat'l
P-616	2998±62	3227*	1277 BC	Old Whaling H-204	53	Char Mtl & Wd

Table II (j)

Pt. Hope
(*Gal 1982, others unpublished from Larsen 1982, written comm.) Ridge position from maps in Larsen and Rainey1948 and Hosley 1972)

Lab. No	14C yrs BP	Calibrated Yrs BP	AD/BC	Culture	Ridge	Context
C-266	912±170	835*	1115 AD	Ipiutak	PH 26	Burial 51
K-2742	1300±70	1268	682 AD	Ipiutak	PH 26	House 3
K-2743	1320±70	1278	672 AD	Ipiutak	PH 27	House 32
K-2744	1290±55	1218*	732 AD	Ipiutak	PH 27	House 43
K-2745	1490±70	1386*	564 AD	Ipiutak	PH 28	House 50
K-2746	1390±70	1306	644 AD	Ipiutak	PH 26	House 69
P-98**	1619±210	1526	424 AD	Ipiutak	--------	-----------
K-724**	1970±100	1911*	39 AD	Near Ipiutak	PH-27	Hearth 2
K-725**	2070±100	2035*	85 BC	Near Ipiutak	PH 27	Hearth 1
K-3543	2050±70	2030*	80 BC	Near Ipiutak	PH-28	Burial 87
K-2741	1790±70	1719	231 AD	Near Ipiutak	PH-28	Midden 25

Table II (k)

Point Barrow Spit Geological Dates--
(Pewe and Church 1962, Brown 1965, Hume 1965)

Lab. No.	Age ^{14}C Yrs. BP	Calibrated Age BP	BC/AD	Material Context (m above sea level)
I-388	1090±140	971	979 AD	Driftwood, 2.9 m below surface, 4.1 m above MSL,
I-387	1100±120	1016*	934 AD	Driftwood, 1.9 m below surface, 4.1 m above MSL
Gx-380	1700±110	1625*	325 AD	2.0 m above mean low water
Gx-381	2365±100	2354	405 BC	1.4 m above mean low water
L-400a	3000±130	3227	1277 BC	raised ridge, 2 km fr. modern beach
Gx-230	5575±375	6374	4424 BC	1.7 m above mean low water

Table III

Archaeological Cultures of Northwest Alaska, used in relative dating for beach ridge complexes (modifying Anderson 1984, 1988, Giddings and Anderson 1986).

Culture	Diagnostic Characteristics	Dates[1]	Distribution
Arctic Small Tool tradition (ASTt) ("Denbigh Flint Complex")	"exquistely" flaked microlithic tools: burinated flakes, endblades microblades oval to sq. houses stone lined hearths: fire cracked rocks seasonal camps on coast: seal hunting	4500 (?) to 3000 BP	Alaska Peninsula to Greenland Type site: Cape Denbigh
Old Whaling	Toggling bone harpoon; Circular houses with entry; notched bifacial points and endscrapers, whalebonedebris, Ground basalt, oil lamps	3200-3000 BP	Kotzebue Sound Wrangel Is.
Choris	Cord & Linear-stamp ceramics Lg.diagonally flaked pts.--"lanceolate; burinization limited Lg. oval houses Ground Slate Flaked adzes Labrets & incised bonework barbed harpoons Pecked stone Oil Lamps Lg. (winter) camps in Mts.--stone lined hearths	3000-2500 BP	NW Alaska (poss.) Chukotka Type Site: Choris Peninsula (SLK-007)

[1]Dates used differ from Anderson's usage, for reasons explained in Mason and Ludwig, in press, this volume, Appendix. Anderson uses Onion Portage dates selectively and postulated the end of ASTt at ca. 3500 BP, a break used to define the beginning of Choris. Similarly, the age of Old Whaling is defined by averaging several dates possibly contaminated with sea mammal old carbon.

Norton	Linear, Check and Plain Ceramics; Great diversity of Proj. Pts., side and end-blades; Discoidal Scrapers; notched stones (for nets); Clay & Stone Lamps; Ground Adz blades sq. , subterranean houses central hearth, tunnel entry	3000-1500 BP	Alaska Peninsula to Mackenzie Delta Type Site: Cape Denbigh Sites numerous on coast & large in scale
Old Bering Sea/ Punuk	Elaborate, linear incised harpoon heads round houses: long entry, check stamp ceramics; shouldered pts. of flaked slate; whalebone burials; use of Iron engraving tools,enigmatic incised winged objects	1800-1000 BP	St. Lawrence Is. Chukotka, Type Sites: Punuk Islands (USA) Ekven/Uelen (USSR) Gambell
Ipiutak	Open work ivory carving Inset eye burials Anthropomorphic designs, LACKS pottery, ground slate; Houses sq. lack tunnels Lithics: side & endblades Lg. coastal settlements	1700-1000 BP	NW Alaska Brooks Range So. Limit: Norton Sound Type Site: Pt. Hope
Birnirk	Multi-spurred harpoons Linear designs Clay pots: Curvilinear stamp; Ground Slate weaponheads	1400-1000 BP	NW Alaska N Chukotka coastal only Type site: Pt. Barrow
Western Thule (incl. Kotzebue Period)	Multi-roomed houses Slate and chipped stone pts., barbed harpoons simple linear decoration Pottery circle or spiral decoration , high percent. of organic artifacts: birch bark, beaver tooth knives	1300 (?) to 200 BP	AK Peninsula to Greenland Type Site: Cape Denbigh

Table IV

Radiocarbon Dates (n=147) from Western Alaska in Relation to the Material D ated (cf. Table II for Dates and Lab Number).

	Charcl	Mix C/Wd	Wood	Marine Mammal	Bone	Shell	Grass	Other
Pt Hope (n=11)	3		3		5			
C Krus (n=33)	11	5	7	7				3
Choris (n=4)	2		1		1			
C Espen (n=37)	29	2		1		2	3	
Wales (n=4)	1		1	2				
Nome (n-9)	9							
Gambell (n=49)			38	11				
TOTAL	55	7	50	21	6	2	3	3
%	**37.4**	**4.8**	**34**	**14.3**	**4.1**	**1.4**	**2**	**2**

PERCENTAGE BY GEOGRAPHIC DIVISION:

BERING SEA **40.1%**
CHUKCHI SEA **59.9%**

53% OF CHARCOAL AT ESPENBERG
76% OF WOOD AT GAMBELL

25% OF TOTAL AT ESPENBERG
22% OF TOTAL AT KRUSENSTERN
33% OF TOTAL AT GAMBELL

Table V

A Sediment Budget Calculation for Cape Espenberg.

1. Volume of Espenberg Complex:

A/B subcomplexes triangular in shape
(12.5 km x 1.5 km x 8 m) x 1/2

Volume:	75×10^6 m^3

C/D subcomplexes
4 km by 1.25 km wide by 5 m thickness
volume: 25×10^6 m^3
plus 2 m above MSL add 10×10^6 m^3

Volume:	35×10^6 m^3

E subcomplex
12 km by 2 km by 5 m deep below MSL:
120×10^6 km^3
add 2 m thickness above MSL
48×10^6 km^3

Volume:	168×10^6 m^3
Plus 2.5 m height above 2 m MSL for 16 km of Unit IV in C, D and E complex	16×10^6 m^3

TOTAL SAND VOLUME AT ESPENBERG:	294 x 106 m^3

2. Sources of Sediment

SOURCE (A) Kitluk River Bluffs

Volume estimate: by averaging 5 m high bluffs over 20 km2.24 km of erosion over 4000 yrs--0.56 m per annum based on Jordan's (1988:341) photogrammetric estimates.

TOTAL VOLUME:	2.24×10^8 m^3
Less 25% for ice content:	1.68×10^8 m^3
Less 75% for silt & clay	33×10^6 m^3 of sand

DIVIDING KITLUK BY TOTAL ESPENBERG:

Hence, Kitluk bluffs contribute about: 11.22%

SOURCE (B) OFFSHORE, subtracting Kitluk contribution:
Offshore sources contribute 88.78%

Error associated with this estimate probably 5 to 10%.

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